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16. ABSTRACT

The Proceedings contains copies of 29 of the 31 papers presented at the Eighth National Symposium on Food Processing Wastes. Subjects included: processing modifications, product and by-product recovery, wastewater treatment, water recycle and water reuse for several segments of the food processing industry. These segments included: red meat and poultry, seafood, dairy, fruit, and vegetable.

Attendance at the two and one-half day Symposium was approximately 200 with good representation by industry, universities, consulting firms, as well as state and Federal agencies.

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March 30 - April 1, 1977
Seattle, Washington

by

Food and Wood Products Branch
Industrial Environmental Research Laboratory
Corvallis, Oregon 97330

Co-sponsored by

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American Meat Institute
Southeastern Poultry and Egg Association
Pacific Egg and Poultry Association
Western States Meat Packers Association
Northwest Food Processors Association
National Independent Meat Packers Association
American Frozen Food Institute

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollution impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The Eighth National Symposium on Food Processing Wastes was co-sponsored with the National Canners Association, American Meat Institute, Southeastern Poultry and Egg Association, Pacific Egg and Poultry Association, Western States Meat Packers Association, Northwest Food Processors Association, National Independent Meat Packers Association and American Frozen Food Institute. The primary purpose of these symposia is the dissemination of the latest research, development and demonstration information on process modifications waste treatment, by-product recovery and water reuse to industry, consultants and government personnel. Twenty-nine papers are included in this Proceedings as well as the final registration list.

These symposia will be continued; if you are interested in participating or wish to receive additional information about the Ninth, contact:

Industrial Pollution Control Division
Industrial Environmental Research Laboratory-Ci
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Cincinnati, Ohio 45268

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Director
Industrial Environmental Research Laboratory
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FROM WHERE I STAND - - -

by

Walter A. Mercer*

INTRODUCTION

The National Canners Association, its officers and members, wish me to express its appreciation and gratitude for the opportunity, over these eight years, to be recognized as a co-sponsor of this National Symposium on Food Processing Wastes. As always, in the past and now, representatives of the Association's Research Staff are pleased to be present and to participate in the program.

The intensive planning which has gone into each of the past seven symposia has resulted in a comprehensive coverage of environmental research dealing with the many facets of water use and wastewater generation in the production and preservation of foods of all kinds.

I am greatly impressed with the number and importance of the co-sponsors listed in this Eighth Symposium program. The fate of the future food supplies of this Nation will be greatly affected by the current and future welfare of these segments of the food industry. Their ability to survive and their willingness to gamble with unpredictable situations, depends on the degree of economic strangulation brought about by emotionally-conceived and hastily-enforced environmental controls.

As I look backward, from this day, near the end of a career of research efforts in a broad area of food industry problems, I recall my participation in the birth and growth of these symposia.

This Eighth Symposium marks a further sincere cooperative, coordinated effort between industry and government to solve a complex of troublesome environmental problems for a number of segments of the food producing and processing industry. The listing of co-sponsors of this Symposium are evidence of that fact.

My experiences in government-industry relations reach back to the days when the U.S. Public Health Service was responsible for quality and pollution abatement research. Through the National Institutes of Health and the Bureau of State Services, I received the first public health research grant ever awarded to a member of an industry-supported research group.

That was 20 years ago. The principal aims of the 8-year period of research support were to make possible and promote water conservation practices in food processing, while protecting and improving, where necessary, the quality and wholesomeness, and sanitation of the canned and frozen foods produced.

---

*National Canners Association, Berkeley, California.

This, and other research, established the basic principles of the counterflow water reuse systems now in use. Included was demonstration of the effectiveness of the controlled application of chlorine to maintain sanitary conditions and the mechanics of more effective application of water in washing and transporting raw foods in preparation for canning or freezing.

During those years, the asparagus, bean, and pea plants of the Pacific Northwest became homes to me--particularly those in the Blue Mountain area of Eastern Washington and Oregon. Later each year the action shifted back to California and its fruit and tomato processing plants.

Now we are faced with a water-shortage crisis and the forced realization that water is a precious commodity whose every drip must be used and re-used now and for all of the years to come.

During the last few weeks old research reports, water reuse diagrams, and conservation recommendations have been dusted off--to be searched through to find if yesterday's answers fit today's problems--or offer a new solution.

Water reuse procedures and waste reduction procedures, developed by yesterday's research, are in use today and have certainly progressed to a degree of sophistication which has assisted the industry in its pollution abatement problems.

If the canning and freezing industry were required, or desired, to use water on a one-pass basis, the annual pack of foods would require an estimated 280 billion gallons of fresh water. Because the industry, many years ago, recognized the need for, and the pollution abatement benefits, of conserving water, it now reuses about 180 billion of its intake water. The final wastewater discharge is approximately 100 billion gallons.

Today, then, there is an estimated 64 percent reuse of processing and container cooling waters in the canning and freezing of foods. This amazing effort to conserve water and reduce liquid waste flows was made possible by government-industry cooperation in years of research which developed and demonstrated the conservation procedures and the chlorination controls necessary for protection of the quality and cleanliness of the foods and the sanitary condition of the food handling equipment.

A question to be answered would cite the current estimate of 64 percent reuse of waters in food canning and freezing and then demand to know why 100 percent reuse and zero discharge of wastewaters cannot now be an industry practice.

First, let me say, that the food processing industry urgently needs and anxiously desires to cooperate in additional industry-government financed research. This could be the means of enabling the industry to further diminish its dependence on water and to lessen its contribution to environmental problems.

Such cooperative research proposals, using as a basis the outstanding results of past cooperative projects, will be proposed. EPA inability or refusal to provide financial and advisory support for sound research proposals is inconceivable. At the focal point of the surrounding circumstances is the welfare of the public, to the degree that it depends on food growing, food preservation, and food distribution.

To accomplish all or a part of the needed research requires further development of in-plant water-saving and waste-prevention equipment or procedural changes--and then of major importance a demonstration, for any and all significant changes, of economical, technological, and sanitational acceptance for application in the processing of foods for human and animal consumption. Extensive re-use of the same water, which approaches closed-loop technology, must be observed, studied, and approved for use by government agencies who regulate the wholesomeness and health safety of foods intended for human and animal consumption.

At this time, recycling of water in contact with food being prepared for preservation cannot come near the closed-loop procedures used in non-food industries. Therefore, if the Federal Water Pollution Control Act adheres to its intent to eliminate all discharge of pollutants by 1985, those food processors able to survive will be few and necessarily large in terms of financial capabilities.

Elimination of food processing plants, however small and however significant to the food production capability of this Nation, has immeasurable and complex adverse social and political consequences. One must recognize that mandated achievement of zero-discharge operations will certainly have the potential for limiting the Nation's food supply and, most importantly, denying an adequate variety of foods to a significant segment of society because the costs are prohibitive.

For my industry, the only hope of approaching, on a broad front, the bureaucratic dream of zero discharge of pollutants would require that tomorrow we begin that complex, sophisticated research which must be done to establish the public health safety and aesthetic acceptability of closed-loop recycling of food processing waters.

Dr. Robert Schaffner, Associate Director for FDA's Bureau of Foods, has made it quite clear that EPA may have assumed, in their Effluent Limitation Guidelines, that the food processing industry will practice extensive recycling of water and the reclamation and reuse of treated wastewaters. However, he clearly stated that the issuing of future regulations for the safe use of recycled waters on foods is FDA's responsibility.

Dr. Schaffner also noted that more research and monitoring is needed to determine the magnitude of the problem of chlorination of recycled waters.

Dr. Schaffner stated that:

"Chloroform and other chloro- or bromo-alkanes seem to be present most oftenm and a wide variety of other compounds may be found whose origin or formation is not understood at this time."

This means that research will have to be undertaken to determine whether or not an extensive water recycle and rechlorination operation in food processing may lead to the formation of such organic compounds.

Such research should be EPA-sponsored, in a typical food industry operation, and I do not refer, here, to treated wastewater for reuse as food processing water.

A PLEA FOR SURVIVAL OF EPA'S FOOD WASTE RESEARCH PROGRAM AT CORVALLIS, OREGON

It is alarming to me, personally, to my associates in food research and production, to associations of food processors, and to consumers, were they adequately informed, to learn that EPA plans to eliminate, for the next fiscal year, funding for further food-oriented research development and demonstration projects. Of great and equal concern are the consequences of a proposed plan of reorganization which eliminates EPA field offices and, thereby, disbands the teams of EPA scientists to whom we have looked for technical advice.

Surely, we have interpreted correctly that portion of the report of the National Commission on Water Quality which gives recognition to the value of EPA scientific input into solving the environmental problems of consumer-dependent, low-profit margin industries in regional areas.

I quote from the Commission's report:

"Finally, the results of many (of the) studies point to a need for technical advisory services to localities and to small industries. The compliance requirements are technically, legally, and administratively complex. The planning requirements and their long-term implications reach beyond the capacity of many small or even moderate-sized communities to cope."

I continue to quote:

"The Commission is convinced that such a field advisory service, operating out of regional offices of EPA would help localities, states, and the Federal government save money. It would halp to expedite grant applications. It would help to assure that communities select the best long-range treatment option, in terms of cost effectiveness and environmental quality. Properly staffed, it could also be an essential information clearing-house to keep localities and industries abreast of innovative technologies and economically and environmentally preferable solutions to their individual treatment problems."

The Commission recommendation and others in the report, are completely in line with my industry's experiences with certain EPA scientists in Washington and most certainly that Food and Wood Products Group in Corvallis, Oregon. I am certain that such statements could be made for other similarly-oriented scientists in other field branch offices of the Agency's current organization.

The Food and Wood Products Branch in Corvallis has, over the past several years, supervised numerous research projects designed to aid the food processing industry's waste management and pollution abatement programs. Since wastes generated during the processing and production of foods are unique--exceptionally high in pollutional strength, highly variable in nature, and frequently seasonal--common technology designed for domestic sewage or other industrial wastes cannot be transferred for application to the treatment of food processing wastes.

Vitally needed information has resulted from the programs supported by the Food and Wood Products Branch. This information has been the basis for the following: (1) process modifications to curtail waste generation, (2) water conservation and wastewater reclamation procedures to reduce water consumption, (3) treatment alternatives to more economically meet pollution abatement regulations, and (4) by-product utilization of waste materials, especially to further the utility of food materials. Although progress has been made in each of these research areas, much work remains to be done to optimize food processing operations to meet environmental goals. This work can only be effectively continued through Federal assistance as administered for the Western States by the EPA scientists in Corvallis.

Due to restrictive compliance schedules legislatively imposed by the Water Pollution Control Act of 1972, the food industry must implement waste abatement procedures which will result in the discharge of specified minimal quantities of water pollutants. The economic impact of these pollution controls is a serious deterent to food production and reasonable consumer costs. Only with continued and intensified research programs can the maximum benefit-cost ratio be achieved for capital expenditures related to pollution abatement. Especially under present economic conditions, consumers and food processors alike can ill-afford imposition of added costs which will result from discontinuities in the current Federal research programs. Every effort must be made to assure that the vitally needed programs are uninterrupted. Continuity in the present staff of the Food and Wood Products Branch is prerequisite to maintaining these programs.

Advantages of the Corvallis Laboratory

In addition to preserving continuity of staff and current programs, continuing the current staff intact at the Corvallis laboratory offers several advantages. Among the principal advantages is its proximity to areas in which certain segments of the food processing industry are concentrated. These centers are evidenced by the large numbers of fruit and vegetable processing plants in the Northwest and California, seafood processing in Alaska and along the Pacific Coast, beet sugar refining plants in the Rocky Mountains, cane sugar plants in Hawaii, and to lesser degrees, the number of meat, poultry, and dairy product plants throughout the western states.

Close proximity to such a wide variety of food processing centers has promoted excellent communication and cooperation between industry and the Food and Wood Products Branch. Environmental problem areas have thus been more readily and better defined, thereby encouraging meaningful research programs. Broader selection of test sites for specific projects has assured the widest possible application of research results--technical and technological developments have had applicability well beyond geographic and commodity considerations. The western states, in which Corvallis is centrally situated, is unique in this important respect.

The Federal food wastes research program as administered by the Branch in Corvallis, by necessity relies heavily on extramural resources, primarily through universities, private research organizations, other governmental agencies, and trade associations. A large number of such institutions, where food wastes research programs are actively conducted, is located in the West.

The universities in Washington, Idaho, Oregon, and California are highly oriented toward agricultural production and food processing; the Sea Grant Colleges in Washington and California, as well as the National Marine Fisheries Services laboratories in Washington and Alaska, are organized to work on seafood processing problems; the U.S. Department of Agriculture's Western Regional Research Center and the National Canners Association Western Research Laboratory have worked in close cooperation with the EPA in developing technical information and new technology for pollution abatement in fruit, vegetable, and seafood processing. The proximity of the Corvallis Branch to these institutions has largely enhanced the implementation of valuable research programs at these locations.

Constant communication between EPA and industry, and between EPA and extramural research institutions, is essential to the continuation of fruitful research. Proximity not only encourages maintenance of such communication, but also promotes frequent personal contact between the Corvallis staff and these outside parties, thereby offering the staff the opportunity to guide and monitor research projects at minimal costs to EPA and to provide continuous development of the staff's expertise in industrial matters. These opportunites will enhance EPA's ability to assure the promulgation of sound and realistic environmental regulations, thereby acquiring maximum benefits for the well-being of both industry and the general public.

The Basis for My Plea

For the food canning industry, we have said in the past and wish to repeat the following:

"The lofty intent of the American public to protect our environment was imperfectly translated into laws by the Congress. Those laws are being imperfectly translated into regulations and the regulations themselves are being imperfectly enforced. In too many cases these successive distractions have resulted in actions which are unrelated to the basic intent of environmental protection.

You who have scientific and technical competence are the ones to whom we must look to keep all of the machinery properly directed. While you may not control the legal machinery itself, you are the advisors upon whom all must lean."

During this past weekend I was shocked and dismayed to read some of the strongly worded statements coming from the headquarters office of EPA, and especially was I disturbed by the Secretary of Interior, who in his Saturday speech to the National Wildlife Federation coined the phrase:

"Rape, ruin, and run."

The Secretary, of course, was referring to alledged misuses of public lands for strip mining, oil development, live stock grazing, and for other purposes.

But if EPA abdicates from its responsibility to continue effective funding for meaningful research in food processing environmental problems, and if the present Food and Wood Products Branch is disbanded and removed from the Corvallis Laboratories, I shall repeat loudly and often that apt phrase:

"Rape, ruin, and run."

EPA Has Established That the Food Processing Industry is Different

The fruit, vegetable, and seafood processing industry in the United States is characterized by extremely wide diversities. This, in fact, applies to all agriculturally-based and agriculturally-dependent industries. The diversities for food canning and freezing plants may be categorized as follows:

---- processing plants vary more than 3000-fold in size, as measured by the tons of raw commodity annually processed

---- the plants are located in wide-spread geographic areas, from the sub-Arctic regions of Alaska to the temperate climate of Florida and Hawaii. Plants sites also vary between the extremes of isolated shoreline locations in Alaska to highly industrialized metropolitan centers

---- processing plants operate for varied periods, depending upon the availability of specific raw commodities; salmon plants in Alaska may operate for just a few weeks, while citrus, potato, and tuna plants may operate for ten or more months per year. Generally, the industry is highly seasonal, with most plants in operation for approximately four months out of the year

---- product mixes (e.g., peas and corn, peaches and pears, salmon and crab, etc.) vary widely between plants, especially in the ratio of commodities processed at each. Thus, waste characteristics, and hence environmental problems, vary among plants within each category (fruit, vegetable, seafood).

These diverse factors, to name but a few, compound the environmental problems facing the food processing industry. Research must therefore be directed not only to general problem areas, but to the specific problems unique to each industrial category. Above all, research programs must include thorough economic analyses, taking the above factors into account, so that cost-effective alternatives may be developed for solving the various environmental problems.

The food processing industry is grateful for the assistance that came in the past--critical problems have been solved. Today's problems are even more critical. Tomorrow will not come for the food industry as we know and depend on it today--unless we strive together--industry and government--to find a way through the economical and technolgical maze that lies ahead.

I shall be deeply troubled if the future brings circumstances which can only be fittingly described by the phrase:

"Rape, ruin, and run."

From Where I Stand--I wish my view of the food industry's future, reflected from the experiences of the past, could be brighter. I know that food processing, with all of its variations, non-standardized systems, and plant-to-plant differences, cannot be stuffed into the EPA-fashioned inflexible mold. There must be a better way. We--EPA and the industry--must find that way together.

STATUS OF EPA'S EFFLUENT GUIDELINES FOR THE FOOD INDUSTRY

by

J.D. Denit* and E.H. Forsht*

INTRODUCTION

Even after five years of working with the statutes, the Federal Water Pollution Control Act Amendments(1) or the FWPCA is still considered by many observers to be one of the most complex and comprehensive measures enacted by Congress. The basic goal of the Act is to "restore and maintain the chemical, physical and biological integrity of the Nation's waters." Also by July 1983, wherever possible, water quality is to be suitable for recreational contact and for the protection and propagation of fish and wildlife.

The basic mechanism of achieving these goals includes an effluent control system to limit discharges of pollutants from point sources into any body of water. Effluent limitations and standards are established so that industrial sources of pollution will have to meet increasingly stringent limitations by the 1977 and 1983 deadlines set in the Act.

By this July, all direct dischargers of pollutants must meet effluent limitations based upon the best practicable control technology currently available (BPT).** This technology represents the average of the best existing waste treatment performance within each industry category or subcategory. However, the Legislative History provides that where waste treatment performance is determined to be uniformly inadequate, the Administrator of EPA may establish effluent limitations on the basis of what the Agency finds is appropriate for BPT in the industry. In such instances, the industry may be held responsible for achieving higher levels of control than any currently in place.

It should be emphasized that determination by EPA that a treatment system (or systems) constitutes BPT does not necessarily require the purchase and installation of that particular equipment. The technology which forms the basis of the effluent limitations are used as reference points only to document the availability of technology which can meet the necessary levels of performance. However, the industry may select alternative methods to meet the effluent limitations. In some plants, for example, implementing waste and water management practices, utilizing by-product recovery techniques, or making changes in process operations may be sufficient to meet the effluent limitations, without the need for end-of-pipe waste treatment. On the other hand, the mere presence of technology which may be defined as BPT does not guarantee that the effluent limitations will be met. It is the industry's responsibility to assure that the appropriate system is installed in a manner designed and sized to accommodate the waste characteristics and flow for individual plants. The treatment units must also be properly operated and monitored to maintain optimum operating conditions.

---

*Branch Chief, Food Industries Branch and Chemical Engineer, respectively, U.S. Environmental Protection Agency, Effluent Guidelines Division (WH-552), Washington, D.C. 20460.

**It should be noted that discharge permits for individual dischargers (normally valid for five years) may have been issued at such a time that they will expire during calendar year 1977. The NPDES permit issuing authority is responsible for such action as necessary to "bridge" the six year period before 1983 limitations are required.

By July 1, 1983 all industrial point sources must meet effluent limitations based on the best available technology economically achievable (BAT). This technology represents the very best control and treatment measures (including in-plant and process changes) that have been developed or are capable of being developed within each industry category or subcategory.

New industrial point sources must meet effluent standards based on the best available demonstrated control technology. These standards include an assessment of what higher levels of pollution control are available through the use of improved production processes as well as end-of-pipe treatment techniques.

Again it should be noted that selection of a particular treatment system as best available or best demonstrated technology, which is used as the basis for effluent limitations or standards, is not tantamount to a technology requirement. Other treatment alternatives can be used to meet the regulations.

CURRENT STATUS OF FOOD INDUSTRY REGULATIONS AND STUDIES

As shown in Table I, the Agency's promulgated regulations cover approximately 28,000 point sources within the food processing industry. These facilities discharge nearly 70 million pounds of BOD5 per day to the receiving waters or to publicly owned treatment works.

The legal status of these regulations are outlined in Table II. Regulations covering 88 subcategories of the food industry have been promulgated. Of these, 32 subcategories are now under judicial review, including 17 subcategories within the grain mills, meat processing and leather tanning categories which the courts have remanded to the Agency for reconsideration of various technical and economic issues.

Table III outlines the status of the remaining food industry studies. The miscellaneous foods category has been divided into the beverages, edible oils, bakeries and confectioneries, and miscellaneous specialty food segments. It is the Agency's intention that regulations for beverages and

TABLE 1. SELECTED CHARACTERISTICS OF THE FOOD INDUSTRY

Category	No. of Dischargers	Flow MGD	BOD5 M lbs./day	Plants meeting BPT
Dairy (2)	5,400	200	4,200	20%
Grain Mills (3)	210	150	610	40%
Fruits & Veg. (4,5)	1,900	470	5,480	75%
Seafood (6,7)	1,400	180	710a	35%
Sugar (8)	130	3,150	2,210	45%
Feedlots (9)	10,000	-	-	-
Meat Prod. (10,11,12)	8,700	5,550	55,400b	65%
Leather (13)	180	50	710	10%
	27,920	9,750	69,320	

a after screening
b after DAF

TABLE 2. LEGAL STATUS OF THE FOOD INDUSTRY REGULATIONS

Category	No. of Subcategories Proposed	Promulgated	Current Litigation	Withdrawn	Remanded
Dairy		11	0		
Grain Mills		10	1		1
Fruits & Veg.		8	3		
Seafood		33	10	5a	
Sugar		8	2		
Feedlots		2	0		
Meat	5	10	10		10
Leather	—	6	6	—	6
	5	88	32	5	17

a 1983 only

TABLE 3. STATUS OF OTHER FOOD INDUSTRY STUDIES

Miscellaneous Food	
Beverages	Proposed in near future
Edible Oils	" " " "
Bakeries & Confectioneries	May be issued as guidance
Misc. Specialities	" " " " "
Meat Products	
Poultry	Anticipate promulgating regulations, but only for 1983 and New Source
Fish Hatcheries	May be issued as guidance

edible oils will be proposed in the near future. However, current resource constraints within the Agency have delayed the economic impact studies for the bakeries and confectioneries, and the miscellaneous specialty food segments. Regulations for these latter two segments and for fish hatcheries and farms are not now anticipated. Instead, technical reports, called Development Documents, will be issued as guidance to permit issuing authorities pending completion of the requisite economic and cost impact studies. The regulations for the poultry subcategories of the meat products category were published in proposed form in the Federal Register on April 24, 1975, however, the Agency anticipates promulgating only the 1983 effluent limitations and new sources and pretreatment standards.

The salient legal issues that have been raised in the judicial review of the cases cited above included jurisdiction (Federal District Court versus the U.S. Court of Appeals) and ranges of limitations for individual plants versus national uniform standards by industrial classes. A recent Supreme Court decision(14) resolved several legal issues regarding the effluent limitations and standards promulgated by EPA. The Supreme Court held that (1) EPA has the authority under Section 301 of the FWPCA "to limit the discharge of pollutants, through industry-wide regulations setting forth uniform effluent limitations, provided some allowance is made for variations in individual plants," and (2) the Courts of Appeals have exclusive jurisdiction to review effluent limitations promulgated under Section 301 which also includes jurisdiction to review guidelines promulgated under Section 304. It is anticipated that the above decision will greatly expedite and eliminate confusion during judicial review procedures.

CHANGING INFLUENCES AND CONSTRAINTS

Changing influences and constraints which may affect the food processing industry regulations include the energy shortage and other environmental legislation.

This winter has highlighted the dismal prognostications regarding the world's energy resources, i. e., our conventional supplies of energy cannot support current levels of consumption. Perhaps these predictions prompted Congress to include the statutory requirements in the Act to consider the energy consumption of the waste treatment technology utilized as the basis for the effluent limitations and standards.

It is not too surprising that a consideration of minimum energy consumption actually encourages production efficiency, waste management and water conservation. Improvements in product and by-product recovery generally divert energy consumption from non-productive waste handling and treatment to production of useful end products. Improved waste management and water conservation practices leads to smaller energy requirements for waste treatment. Smaller treatment systems require fewer resources for production and installation. Likewise, pumping smaller volumes of effluents through or among treatment units requires less energy.

At the present time, the Agency is assessing various issues regarding a strategy to strengthen overall environmental protection under effluent guidelines through consideration of the impact of the Resource Conservation and Recovery Act(15) and the Safe Drinking Water Act(16). The Resource Conservation and Recovery Act provides for R & D and dissemination of information on promising recovery, disposal, and resource use techniques. The Agency must also issue criteria for identifying hazardous wastes and require a permit for any facility which treats, stores, or transports hazardous wastes. The Safe Drinking Water Act is designed to assure that water supply systems serving the public meet minimum national standards for protection of public health. This Act also establishes a joint Federal-State system for protecting underground sources of drinking water.

One example of the inter-relationship among these Acts revolves around the "zero discharge" effluent limitations established for various point source dischargers including some within the food processing industry. In assessing this requirement in relation to the Safe Drinking Water Act, two points are particularly pertinent. First, ground water is the drinking water source for at least 50 percent of the American population. The majority of this ground water is not treated prior to use as drinking water. Second, the Safe Drinking Water Act is designed to protect both surface and ground sources of drinking water from initial contamination wherever possible. Correspondingly, the Resource Conservation and Recovery Act mandates the protection of both ground and surface waters from leachates from any solid waste disposal project. Disposal is defined as "the discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including ground water."

As a practical matter, many dischargers may attempt to meet the "no discharge" limitations by disposing of untreated wastes into an unlined pond or lagoon. If the surrounding area is permeated by an aquifer which could be a drinking water source, potential leachates could create serious environmental problems. In fact, leaching from holding ponds and lagoons is the second major source of ground water pollution next to septic tanks and cesspools.

In some cases, particularly those involving hazardous materials, a zero discharge standard may raise consequent questions as a solution to the problems posed by water pollution. In other cases "zero discharge" in arid regions may also complicate the essential balance between beneficial uses downstream and water conservation efforts which are strongly supported by states, environmental groups, and farmers.

Even with limitations which allow a discharge of pollutants, one must consider the implications for sludge disposal and effluent discharge to ground or surface waters. In fact, the Agency's current efforts include developing strategies to incorporate a close scrutiny of all intermedia effects into subsequent reviews of the effluent limitations and standards.

RECOVERY, REUSE, AND CONSERVATION

These changing influences and constraints which include other environmental laws and declining resources, confirm the truth in the old maxim that recovery, reuse, and conservation are essential to pollution control, resource utilization and economic efficiency. The food processing industry in general, as exemplified by many segments of the meat processing industry, should reorient its efforts toward a "total utilization concept," wherein much of the current waste materials are viewed as "secondary raw material." This approach closes the processing cycle so that raw material is used to the fullest extent possible with the subsequent minimization of environmental pollution. The implementation of in-plant changes to accomplish this goal is certainly more logical than spending large amounts of money to simply treat food processing wastes at the end of the effluent pipe.

Successful examples of these concepts include:

a) Recovery of animal and fish solid wastes as well as dissolved and suspended nutrients for animal feeds, tallow, inedible products, or low grade fertilizers;

b) Recovery of potato, orange, grapefruit, and pineapple peel wastes as animal feeds, and

c) Recovery of whey solids for use in other food products.

Likewise successful water conservation techniques which may apply to the food processing industry include:

a) Teaching good water management practices to plant operators;

b) Utilizing dry solids transportation rather than wet fluming;

c) Recycling or reusing water; and

d) Implementing dry clean-up operations prior to water washes.

FUTURE CONCERNS

As a practical matter, the future of the food processing regulations contains the uncertainties associated with possible legislative amendments to the FWPCA, and the new administration's approach to environmental issues.

Congress is now considering many proposals from industry, labor, agriculture, environmental, and government groups for amendments to the FWPCA. The Environmental Protection Agency has submitted several proposals which would directly affect industry. These include:

a) inserting a new section authorizing the imposition of a fee upon non-complying point sources. The fee would approximate the economic value of non-compliance to equalize the competitive positions of the cooperative and recalcitrant point sources;

b) amending section 509(b) to modify the location for judicial review of a number of EPA actions under the FWPCA so that petitions for review may be filed only in the United States Court of Appeals for the District of Columbia. Such a provision finds precedent in the Clean Air Act and would prevent "forum shopping" which often results in inconsistent interpretations of the Act and issues of nationwide importance; and

c) amending section 308 to provide that contract employees of EPA would be permitted to excercise the functions of an "authorized representative" as the Congress intended when it enacted section 308.

The Agency has advised against extension of the July 1, 1977 deadline for industrial point sources, because most of the major industries will be in compliance by that date. Those industries unable to meet the deadline because of factors beyond their control will be eligible to receive EPA Enforcement Compliance Schedule Letters that require compliance by a specified date. Despite the recommendations of the National Commission on Water Quality, the Agency sees no need to extend the 1983 deadline since Section 301(c) provides for economic variances from the BAT requirements where appropriate.

Based on campaign issues, papers and recent statements, it appears as if President Carter will play an active role in environmental issues and legislation. The President has stated that "we must vigorously enforce the pollution control... laws already on the books."(17) He also believes that much of the environmental damage which now occurs can be prevented and has pledged his support for research to find environmentally sound ways to achieve economic goals without unacceptable pollution damage. The President also believes that it is not possible to discuss environmental pollution without considering energy. Several elements of the President's energy policy relate directly to the environment. As an integral part of energy conservation, industry needs "to make better use of recycled materials, to better manage our solid wastes, and to realize the fuel savings which recycling offers".(17)

SUMMARY

These recent trends in environmental issues suggest that, regardless of the outcome of individual court cases or the proposals for amendments to environmental legislation, the industrial sector is expected and must continue to reduce the levels of pollutants into the environment.

Industry should evaluate every waste treatment alternative which is technically and economically feasible, not just the technology which forms the basis for the effluent limitations and standards. The Agency intends to continue working to integrate its efforts to help minimize the intermedia environmental consequences of its regulations. Correspondingly, the optimum environmental approach which typically includes by-product recovery, reuse, recycle, and conservation along with end-of-pipe treatment, is increasingly consistent with industry's economic self-interest.

REFERENCES

1. Federal Water Pollution Control Act Amendments of 1972, P.L. 92-500, October 18, 1972, 33 USC 1251, et. seq.

2. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Dairy Product Processing Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, May 1974, EPA-440/1-74-021-a.

3. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Grain Processing Segment of the Grain Mills Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, March 1974, EPA-440/1-74-028-a.

4. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Apple, Citrus, and Potatoes Segment of the Canned and Preserved Fruits and Vegetable Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, March 1974, EPA-440/1-74-027-a.

5. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Fruits, Vegetables and Specialties Segment of the Canned and Preserved Fruits and Vegetables Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, October 1975, EPA-440/1-75/046.

6. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Catfish, Crab, Shrimp and Tuna Segment of the Canned and Preserved Seafood Processing Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, June 1974, EPA-440/1-74-020-a.

7. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Fish Meal, Salmon, Bottom Fish, Clam, OyOter, Sardine, Scallop, Herring and Abolone Segment of the Canned and Preserved Seafood Processing Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, September 1975, EPA-440/1-75/041a.

8. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Beet Sugar Processing Subcategory of the Sugar Processing Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, January 1974, EPA-440/1-74-002-b.

9. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Feedlots Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, January 1974, EPA-440/1-74-004-a.

10. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Red Meat Processing Segment of the Meat Product and Rendering Processing Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, February 1974, EPA-440/ 1-74-012-a.

11. Development Document For Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Processor Segment of the Meat Products Point Source Category, U.S. Environmental Protection Agency Wash., D.C., 20460, August 1974, EPA-440/1-74/031.

12. Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Poultry Segment of the Meat Product and Rendering Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, April 1975, EPA-440/1-75/031-b.

13. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Leather Tanning and Finishing Point Source Category, U.S. Environmental Protection Agency, Wash., D.C., 20460, March 1974, EPA-440/1-74-016-a.

14. E.I. duPont de Nemours & Co., et. al. v. Train, Administrator, Environmental Protection Agency, et. al., 97 S. Ct. 965 (1977).

15. Resource Conservation and Recovery Act of 1976, P.L. 94-580, October 21, 1976, 42 USC 6901, *et*. *seq*.

16. Safe Drinking Water Act, P.L. 93-523, December 16, 1974, 42 USC 300 f., *et*. *seq*.

17. Carter, Jimmy, "My Views on the Environment", *EPA Journal*, Vol. 3, No. One, January 1977.

EFFLUENT POLISHING AND WASTEWATER REUSE AT SNOKIST GROWERS CANNERY

by

Larry A. Esvelt*, Herbert H. Hart**

INTRODUCTION

Snokist Growers is a growers cooperative located in Yakima, Washington which markets fresh and canned fruit to wholesale and retail outlets. The cooperative owns and operates a cannery to produce canned pears, peaches, cherries, plums, and apple slices, sauce and rings. A normal processing season consists of about 9 weeks production of pears at about 250 metric tons raw fruit per day, a week of peach canning at about 250 metric tons raw fruit per day, 15 weeks of apple processing at about 100 metric tons of raw fruit per day, and varying cherry and plum production depending on the season.

In 1968 Snokist Growers Cannery placed a biological wastewater treatment system in operation which has consistently produced an effluent well within their State and EPA discharge permit. It was evaluated under an EPA grant (1,2,3) and was subsequently used as an exemplary waste treatment system during the development of 1977 best practicable treatment guidelines for food processing wastewater discharges. In 1973, a low water year, Snokist management became concerned about the integrity of their water supply system which appeared to be diminishing due to ground water levels dropping at their wells and decided that additional water sources were needed. They then investigated the feasibility of an additional well and of reclaiming a portion of their biologically treated process effluent for use in the cannery. No sanitary wastes enter the processing wastewater stream, minimizing the potential for human pathogen presence in the wastewater. The lower cost alternative was development of a new well supply but word of the consideration of reclaiming effluent reached EPA officials in charge of evaluating the possibility of reducing food processing wastewater emissions through reclamation and recycle in compliance with PL 92-500. They suggested the possible availability of R & D funds to provide Snokist with economic incentive to select the effluent reclamation and reuse alternative rather than developing a new well water supply. Snokist then applied for an R & D grant and received EPA grant number S803280 in late 1974. The grant was to partially offset the cost differential between the two alternatives and to finance evaluation of the reclamation and reuse of treated processing wastewater. Harold Thompson of the EPA, Corvallis, OR has served as Project Officer.

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Objectives for EPA R & D Project S803280 were as follows:

1. Determine the feasibility of treating fruit processing wastewater to achieve a suitable water quality for in-plant reuse and to develop operational procedures to ensure consistent performance of the treatment facility.

2. Determine the feasibility of reusing the treated fruit processing wastewater for:
   a) Equipment cleaning
   b) Product cleaning and conveying
   c) Boiler feed to produce steam for:
      1) Cleaning
      2) Exhausting
      3) Cooking
      4) Blanching
   d) Direct contact container cooling

3. Document the reduction of pollutants being discharged to the environment resulting from the reuse of treated processing wastewater and evaluate the economics of wastewater reuse for achieving EPA's 1983 effluent standards.

Facilities for biological effluent polishing were installed in 1975 and were used to provide reclaimed effluent for reuse during the 1975 and 1976 process seasons. The reclaimed effluent quality was routinely monitored for chemical and biological quality. Special testing was conducted to ascertain the level of specific pollutants such as heavy metals, pesticides, halogenated organics and pathogens.

Use of the reclaimed water was routinely applied to floor and gutter wash and applied to the uses to be evaluated under the project objectives for varying periods. The results of such uses on product quality was assessed.

WASTEWATER TREATMENT FACILITIES

Snokist Growers cannery wastewater treatment facilities were constructed in 1968 to accomodate a flow up to 2.5 mgd and BOD of 28,000 lb/day. A schematic flow diagram for the treatment system is shown on Figure 1. Table 1 describes the system components. The activated sludge system produced a high quality effluent for discharge to the Yakima River (1,2,3).

Before the 1975 processing season additional facilities were added to polish the biologically treated effluent by multimedia filtration and disinfection. The flow schematic during the 1975 and 1976 processing seasons is shown on Figure 2. The facilities added for the wastewater reclamation and reuse are listed in Table 2.

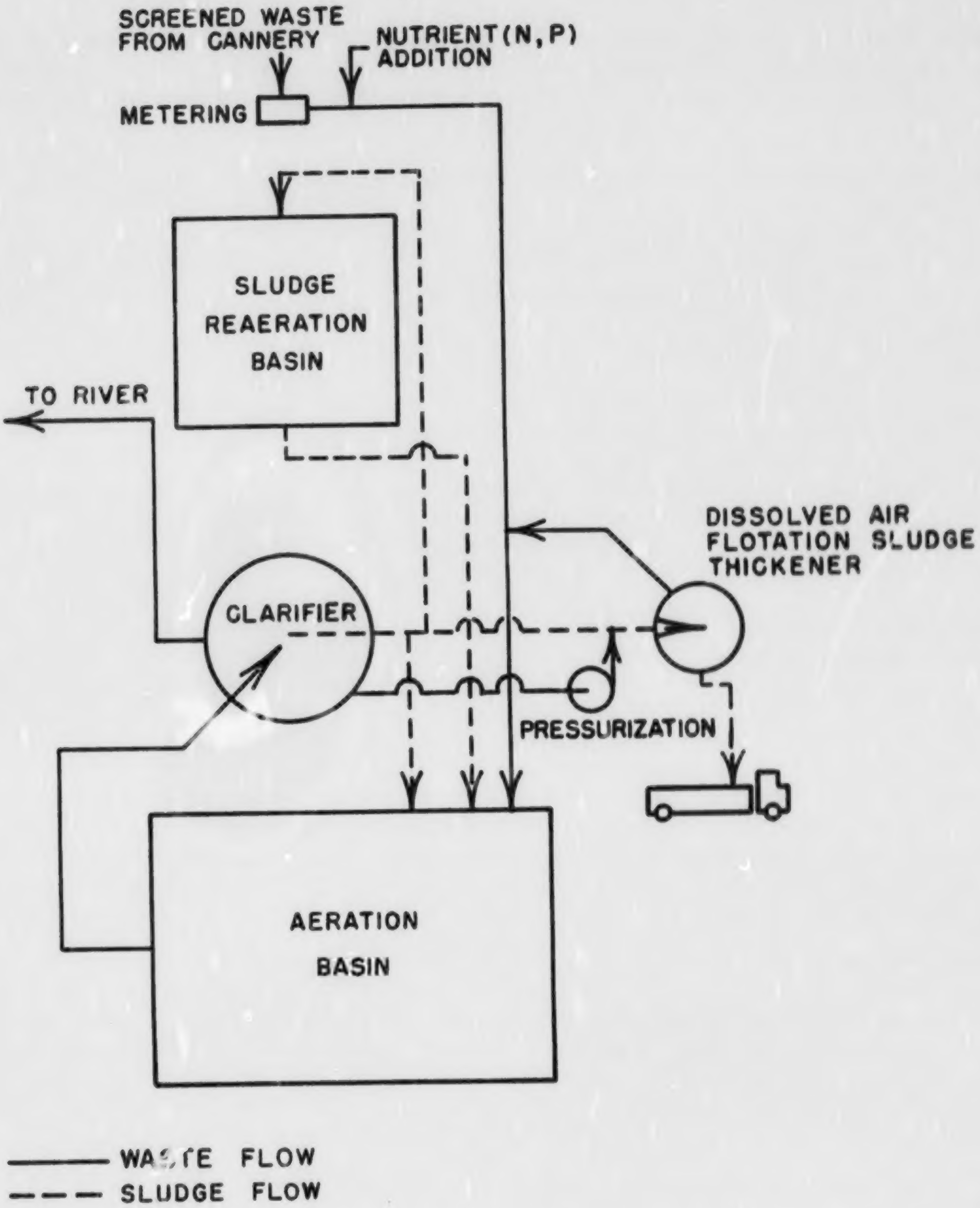
SCREENED WASTE FROM CANNERY
NUTRIENT (N, P) ADDITION
METERING
SLUDGE REAERATION BASIN
TO RIVER
DISSOLVED AIR FLOTATION SLUDGE THICKENER
CLARIFIER
PRESSURIZATION
AERATION BASIN
WASTE FLOW
SLUDGE FLOW

Figure 1. Snokist Growers Wastewater Treatment System Schematic Flow Diagram 1968 - 1974.

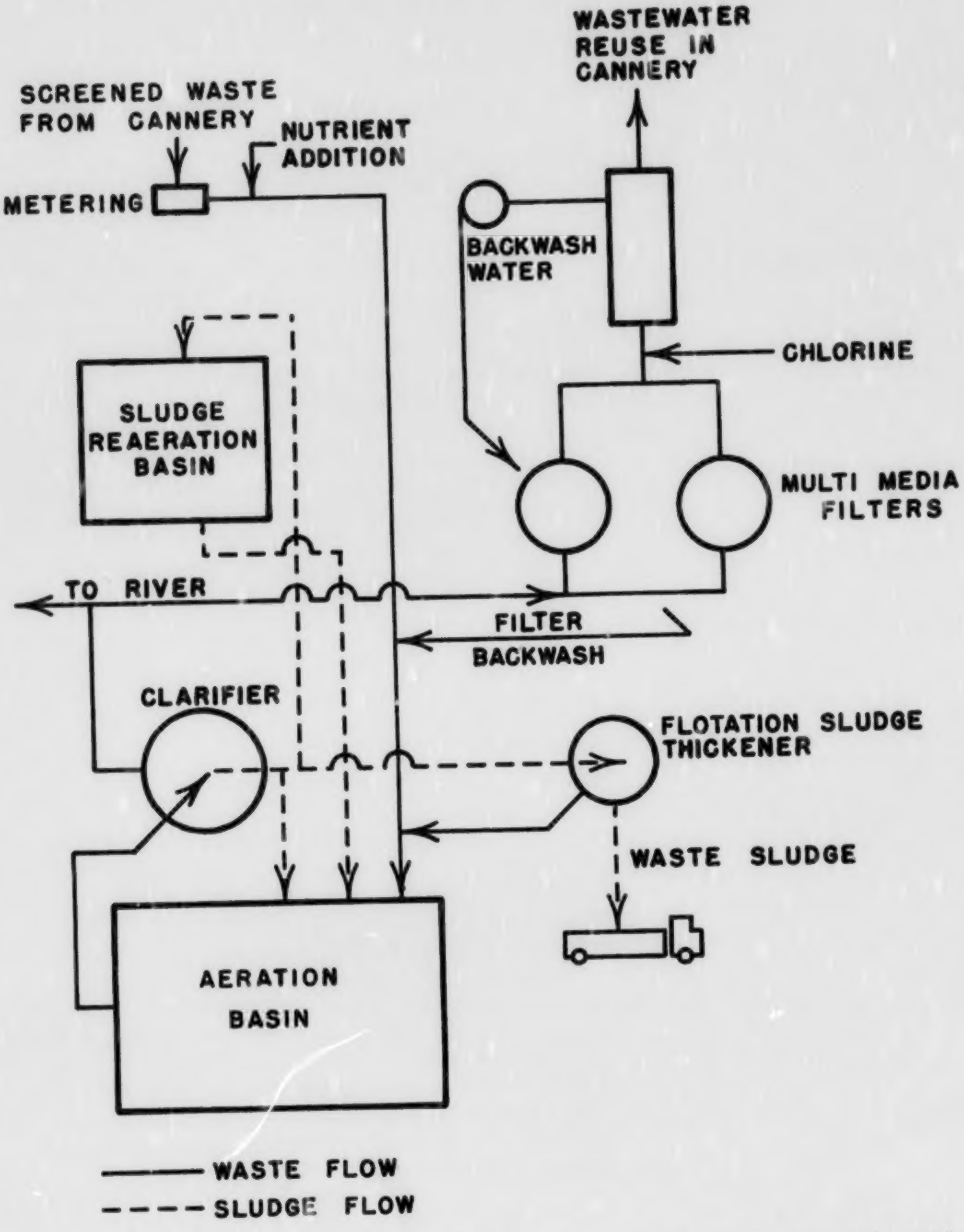
WASTEWATER REUSE IN CANNERY
SCREENED WASTE FROM CANNERY
NUTRIENT ADDITION
METERING
BACKWASH WATER
CHLORINE
SLUDGE REAERATION BASIN
MULTI MEDIA FILTERS
TO RIVER
FILTER BACKWASH
CLARIFIER
FLOTATION SLUDGE THICKENER
WASTE SLUDGE
AERATION BASIN
WASTE FLOW
SLUDGE FLOW

Figure 2. Snokist Growers Wastewater Treatment System Schematic Flow Diagram 1975 - 1976.

TABLE 1. SNOKIST GROWERS WASTEWATER FACILITIES

Facility	Description
1. Screening	8 mesh/cm (20 mesh/in) vibrating screens
2. Aeration Basin	22,700 cubic meter (6 million gallon) earthen dike, PVC lined basin with 5 surface aerators having a total of 292 kw (390 horsepower)
3. Clarification	27.5 meter (90 ft.) Diameter, hydraulic sludge removal, 2.4 m (8 ft.) side water depth, center feed.
4. Sludge Recirculation	Two variable speed pumps each with 6,600 liter per minute (1750 gallon per minute) capacity
5. Sludge Reaeration	5,700 cu. meter (1.5 million gallon) basin with 45 kw (60 horsepower) surface aeration
6. Sludge Thickening	9.2 meter (30 ft.) Diameter pressurized recycle flotation sludge thickener

TABLE 2. SNOKIST GROWERS WASTEWATER POLISHING FACILITIES CONSTRUCTED 1975

Facility	Description
1. Filters	Two 2.4 meter (8 ft.) diameter by 1.8 meter (6 ft.) side pressure filters. Area= 4.7 sq. meters (50 sq. ft.) each. Media = Microfloc MF 177 - 90.5 mm (36 in.) filter: 30% 1.5 sp. gr. anthracite (3mm); 30% 1.6 sp. gr. anthracite; 30% 2.6 sp. gr.silica sand; 10% 4.0 sp. gr. garnet sand (0.25 mm) supported on 3 inches of 1-2 mm 4.0 sp. gr. sand and 11 inches graded silica gravel. Equipped with pipe underdrain, surface wash, pneumatically operated automatic valves, automatic backwash program, flow, headloss meters and automatic flow control.
2. Turbidity Meter	Low range, continuous flow - Hach CR
3. Filter and Backwash Pumps	Two constant speed 3800 liter (1000 gal) per min @ 20 meter (66 ft.) TDH/2600 liter (700 gal) per min. @ 23 meter (75 ft.) TDH pumps, interchangeable. 22.5 KW

TABLE 2. Continued

4. Chemical Feed Pumps	Liquid alum storage and automatic stroke adjustable feed pump. Polymer stroke adjustable feed pump. To be used if needed.
5. Reclaimed Water Pump	Split case 2600 liter (700 gal) per min @ 54 meter (177 ft.) TDH pump. 37 KW.
6. Chlorinator	One 227 kg (500 lb.) per day chlorinator with motorized "V-notch" control valve and motorized vacuum valve for "compound loop" control.
7. Chlorine Residual Analyzers	Two wastewater type amperometric continuous flow analyzers for monitoring and controlling chlorine residual at the filter effluent and for monitoring chlorine residual at the reclaimed water pump inlet.
8. Chlorine Contact Chamber and Backwash Water Storage	Two hundred twenty seven cu. meter (60,000 gal) baffled chamber - 11.6 meters (38 ft) X 6.7 meters (22 ft) x 3 meters (10 ft) deep with 6 baffles.
9. Controls and Operation	a. Flow to filters automatically maintained according to chlorine contact level up to a preset maximum rate per filter. b. Filter backwash initiated by timer, high head loss across filters or manually. c. Chlorine residual automatically maintained by flow proportioning and residual monitoring and feed rate adjustment. d. Chemical feed of alum and/or polymers, if used, paced to filter flow. e. Reuse pump automatic shutdown at low contact tank level. f. Alarms transmitted to wastewater lab and plant for appropriate action due to following: 1) Low or high chlorine residual in reclaimed water 2) High turbidity in filtered water 3) Low contact tank/backwash storage level 4) System malfunction

STUDY OF WASTEWATER REUSE

The wastewater treatment system performance was monitored for performance during the 1974, 1975 and 1976 processing seasons under this study. Monitoring points included the screened wastewater, aeration basin effluent, clarifier effluent, filter effluent and chlorinated reclaimed wastewater reused in the cannery. Snokist Growers tested the wastewater for temperature pH, COD, BOD, suspended and volatile suspended solids, nitrogen, phosphorus, turbidity, chlorine residual, hardness, alkalinity, total bacterial plate count and total and fecal coliform bacteria at various of the monitoring points. Samples from the reclaimed wastewater, and from Snokist's water supply for comparison, were analyzed by National Canners Association for heavy metals, by the Environmental Protection Agency Region X Laboratory for pesticides and volatile halogenated organics, by Foremost Laboratories for volatile halogenated organics, by Dohrmann Laboratories for total halogenated organics and by Columbia Laboratories for herbicides.

The reclaimed water was used in the cannery for floor and gutter wash throughout the 1975 and 1976 processing seasons. Trial uses of the reclaimed water were for equipment washdown, initial product conveying, contact container cooling and generation of steam for use in equipment washdown, exhausting, cooking and blanching. The effect of using the reclaimed water for these purposes was compared with using the regular house water supply. Total Plate Count of bacteria was used to compare the effect of using the alternate waters and steam sources for washing peelers and belts on parallel pear processing lines. Total Plate Count was also used to compare the reclaimed and house waters for use in bin dump tanks and initial conveying of peaches and apples. The counts were taken of the water in the dump tank and of water used to rinse the fruit (a standard number of fruit in a standard amount of water) before and after contact with the dump and conveying water. Cans of fruit cooled in the two waters under similar conditions were stored for a given time period and observed for failure. Product quality evaluation by grading (USDA Grades) and organoleptic comparison was used to compare steam from the reclaimed water source with house steam.

RESULTS

Snokist Growers cannery process wastewater flow rate during pear and peach processing averaged from 5,500 to 6,500 cu meters/day (1.5 to 1.7 mgd) during the 1974, 1975 and 1976 processing seasons and 2,500 to 3,500 cu. meters/day (0.7 to 0.9 mgd) during apple processing. The untreated wastewater COD during pear processing averaged over 2000 mg/l in 1974, about 1800 mg/l in 1975 and about 1500 mg/l in 1976. The reduction from 1974 to 1975 resulted from additional water use from recycled effluent for floor and gutter wash. From 1975 to 1976 water use was cut back slightly and peel and core solids were removed separately resulting on a lower waste load in the effluent to the treatment system.

The wastewater is nutrient deficient so nitrogen and phosphate are added prior to treatment. The aerators maintain over 2 mg/l dissolved oxygen in the activated sludge system and the sludge recirculation rate approximately equals the process wastewater flow rate.

The treatment system performance was monitored over the three seasons. Effluent emission rates are shown on Tables 3,4, and 5. The tables show that variations in emission rates occurred from week to week. The tables also show that the emission rate for suspended solids and COD actually increased from 1974 to 1975 even though over 30% of the effluent was recirculated for use in the cannery during 1975 and the amount of wastewater discharged reduced by nearly 30% on a per unit of product basis. The biological effluent was of poorer quality in 1975 than in 1974 and the reason was thought to be increased chlorine useage in the cannery for cleanup which allowed chlorinated slugs to reach the aeration system at startup each morning.

During the 1976 season additional attention was given to control of inplant chlorination which resulted in better biological effluent quality and reduced emission rates for suspended solids, COD and BOD throughout pear processing except for one week immediately following Labor Day (September 6). The biological treatment system was apparently hit by a highly toxic slug of accumulated chlorinated washdown from belts and equipment at startup on September 7. The system recovered rapidly when reseeded with the contents of the small aeration basin.

The emission rates for pollutants jumped sharply in 1976 when pear processing ended and apples only processing was initiated. The plant may have been receiving occasional chlorinated slugs but the principal reason for effluent deterioration is thought to be the onset of cold weather at about the same time. From near the end of November 1976 through January 1977 the aeration basis did not exceed 2^{O} Celcius.

TABLE 3.

1974 POLLUTANT EMISSIONS
SNOKIST GROWERS WASTEWATER REUSE PROJECT
PROGRESS REPORT

Week	Fruit Processed* kkg	COD Emission		BOD** Emission kg/kkg	Suspended Solids Emission	
		Total kg	kg/kkg Fruit		Total kg	kg/kkg
8/23-24	518 Pr	1590	3.07	-	1050	2.03
8/26-31	1616 Pr	4520	2.80	3.00	1430	0.88
9/3-7	1319 Pr	1030/4 da	0.98	0.06	189/4 da	0.18
9/9-14	1305 Pr,121 Pl	1025	0.72	0.06	229	0.16
9/16-20	624 Pr,426 Pl	810	0.77	-	230	0.22
9/23-28	1636 Pr,236 A	1000	0.53	0.07	450	0.24
9/30-10/5	1600Pr,519A,20Pl	765/5 da	0.43	--	309/5 da	0.17
10/7-12	1546 Pr,587 A	1830	0.86	-	785	0.37
10/14-19	1588 Pr,595 A	1750	0.80	0.20	486	0.22
10/21-26	1618 Pr,592 A	1930	0.87	0.15	825	0.37
10/29-11/2	1335 Pr, 538 A	770/3 da	0.69	0.13	473	0.25
11/4-9	1438 Pr, 576 A	1095	0.54	0.09	428	0.21
11/11-15	648 A	1260	1.94	0.64	474	0.73
11/18-22	819 A	770/4 da	1.18	0.09	140/4 da	0.21
11/25-27	234 A	255	1.09	0.14	136	0.58
12/2-6	386 A	4440***	11.5	0.19	3530***	8.63
12/9-13	295 A	540	1.83	0.16	310	1.05

* Pr = Pears, Pe = Peaches, Pl = Plums, A = Apples
** 1 day or 2 days during week only
***1 day high results skewed results

Total Wastewater Flow 8/23 - 12/13/1974 = 460,600 cu.m.
Total Fruit Processed 8/23 - 12/13/1974 = 22,800 kkg
Wastewater Discharge Rate = 20.2 cu.m./kkg (4770 gal/ton)

TABLE 4.

1975 POLLUTANT EMISSIONS
SNOKIST GROWERS WASTEWATER REUSE PROJECT
PROGRESS REPORT

Week	Fruit Processed* kkg	COD Emission Total kg	COD Emission kg/kkg Fruit	BOD** Emission kg/kkg	Suspended Solids Emission Total kg	Suspended Solids Emission kg/kkg Fruit
8/26-30	1407 Pr	1300	0.92	0.16	592	0.42
9/2-6	1358 Pr	880	0.65	0.076	346	0.25
9/8-13	1664 Pr, 46 Pl	1940	1.13	0.22	817	0.48
9/15-20	1644 Pr, 520 Pl	1700	0.79	0.12	625	0.29
9/22-27	1311 Pe, 280 Pl	1330	0.84	0.105	630	0.40
9/29-10/4	1734 Pr, 14 Pl	1230	0.70	0.070	627	0.36
10/6-11	1620 Pr, 473 A	4240	2.03	0.31	3290	1.57
10/13-18	1598 Pr	3320	2.08	0.38	2230	1.40
10/20-25	1666 Pr, 550 A	2590	1.17	0.14	1590	0.72
10/28-11/1	1334 Pr, 498 A	1190	0.65	0.054	482	0.26
11/3-8	1730 Pr, 570 A	1990	0.87	0.13	829	0.36
11/10-15	1670 Pr, 682 A	1130	0.48	0.115	505	0.21
11/17-19	789 Pr, 397 A	350	0.30	0.033	88	0.074
11/20,21,24,25	570 A	362	0.64		125	0.22
12/1-5	840 A	1540	1.83	0.39	1035	1.23
12/8-12	881A	1070	1.21	0.25	585	0.66
12/15-18	291 A	455	1.56	0.26	161	0.55

*Pr = Pears = Pe = Peaches, Pl = Plums, A = Apples
**1 day per week only

Total Wastewater Flow 8/26-12/19/75 = 557,500 cu.m
Total Wastewater Reused = 180,100 cu.m.
Total Effluent to River = 377,400 cu.m.
Total Fruit Processed 8/26-12/19/75 = 26,500 kkg
Wastewater Flow Rate = 21.0 cu.m./kkg (4970 gal/ton)
Effluent Flow Rate = 14.2 cu.m./kkg (3360 gal/ton)

TABLE 5.

1976 SEASON POLLUTANT EMISSIONS
SNOKIST GROWERS WASTEWATER REUSE PROJECT

Week	Fruit Processed kkg	COD Emission Total kg	COD Emission Unit kg/kkg	BOD** Emission kg/kkg	Suspended Solids Emission Total kg	Suspended Solids Emission Unit kg/kkg
8/24-8/28	1529 Pr	449	.326	.078	172	.112
8/30-9/4	1760 Pr	514	.292	.027	118	.067
			(5.2 max da)			(1.09 max da)
9/7-9/11	1520 Pr	3854	2.54	.464	1022	.672
9/13-9/18	1622 Pr, 473 Pl	742	.354	.052	196	.094
9/20-9/25	1601 Pr, 482 Pl	1020	.490	.133	309	.148
9/27-10/2	1490 Pr, 29 Pe, 14 Pl	610	.398	.039	147	.096
10/4-10/9	1828 Pr, 529 A	694	.294	.027	211	.090
10/11-10/16	1808 Pr, 563 A	772	.326	.030	232	.098
10/18-10/23	1830 Pr, 551 A	845	.355	.053	362	.152
10/25-10/30	1674 Pr, 569 A	1001	.446	.041	295	.132
11/1-11/6	1744 Pr, 575 A	957	.413	.044	403	.174
11/8-11/13	1452 Pr, 459 A	1146	.600	.099	364	.190
11/15-11/20	646 A	584	.904	.066	155	.240
11/22-11/24	422 A	408	.967	.137	178	.423
11/29-12/3****	566 A	1127	1.99	.336	751	1.33
12/6-12/10***	714 A	867	1.21	.245	606	.849
12/13-12/17***	728 A	602	.827	.165	366	.503
12/20-12/22***	418 A	470	1.13		266	.636
12/27-12/30***	549 A	315	.574		149	.271
1/3-1/7****	678 A	573	.845	.111	488	.720
1/12-1/14****	397 A	2797	7.05		686	1.73
1/17-1/21****	741 A	4460	6.02		1627	2.20
1/24-1/28 & 1/31***	958 A	1938	2.02	.57	1277	1.33
2/23-2/25***	391 A	570	1.46		439	1.12
2/28-3/4	588 A	709	1.21	.238	449	.764
3/7-3/10	494 A	238	.482	.047	140	.283

* Pr = Pears, Pe = Peaches, pl = Plums, A = Apples
** One or two days per week data only
*** Aeration Basin Temperature less than 2°C
**** Aeration Basin partially or completely frozen over

(Continued)

TABLE 5.(Continued)

	8/24-11/13	11/15-3/10
Total Wastewater Flow, cu. m.	422,720	209,750
Total Wastewater Reused, cu. m.	159,660	60,340
Proportion Reused	37.8%	28.8%
Total Effluent to River, cu. m.	263,060	149,410
Total Fruit Processed, kkg	24,102	8,290
Wastewater Flow Rate, cu. m./kkg	17.5	25.3
Wastewater Flow Rate, gal./ton	4,210	6,080
Effluent Flow Rate, cu. m./kkg	10.9	10.9
Effluent Flow Rate, gal./ton	2,617	4,330

Overall proportion reused = 34.8%

Overall Effluent Flow Rate = 12.7 cu. m./kkg
3,060 gal./ton

Reclaimed Water Quality

The reclaimed effluent quality is highly dependent upon the biological effluent quality. Figure 3 shows the frequency distribution for the biological and filtered effluents during the pear processing season of 1974, 1975 and 1976. Generally the filter system is effective at reducing the suspended solids, but only by about 30 to 50% and then only when the solids load to the filters is relatively low. Figure 3 shows the relatively poorer effluent and reclaimed water produced in 1975 compared with the other years.

The chlorination system was effective at disinfecting the reclaimed water. Figure 4 shows a frequency distribution for chlorine residual and total and fecal coliform organisms in the reclaimed effluent during the 1976 season. The poorest disinfection results occurred during the week of biological system upset following Labor Day when chlorine demand exceeded chlorination capacity. Other poor disinfection results occurred when equipment malfunctions allowed the chlorine residual to fluctuate. Figure 4 indicates that the chlorine residual maintained at 3 mg/l resulted in less than one total and fecal coliform organism per 100 ml. A chlorine residual of 2 mg/l resulted in total coliform organism concentration of about 2 per 100 ml or less. Analyses for Salmonella and Staphylococcus organisms were negative.

Heavy metals analyses were conducted on the reclaimed water and compared with Snokist Growers cannery house water supply (ground water). Iron, arsenic, cadmium, tin and manganese were consistently below the detectible limits in both waters. Lead was consistently below detectible limits in the house water but was detected at 0.01 and 0.02 mg/l in two of five samples of reclaimed water analyzed in 1976. Mercury was found at from 0.0003 to 0.0009 mg/l in 4 samples of reclaimed water and was not detectable in 4 samples. Mercury was 0.0003 to 0.0010 in three house water samples and undetected in two samples. One sample of each analyzed on the same day showed high mercury levels (0.0026 and 0.0017 mg/l in reclaimed and house water respectively) which is assumed to be analytical error. Zinc concentrations ranged from 0.15 to 0.63 mg/l in the reclaimed water and from less than 0.01 to 0.02 mg/l in the house water.

Pesticide and PCB analyses were performed by the EPA Region X laboratory. All results were less than the detectable level except PCB's which were detected in the house water on four occasions in 1976 at up to 0.065 micrograms per liter.

Analyses for organohalides was conducted by Foremost and Dohrmann Laboratories in California in 1976. Chloroform in the chlorinated reclaimed effluent ranged from 1.5 to 25 micrograms per liter while other volatile organohalides were at or below 1 microgram per liter. Total volatile organic halides were measured at about 13 mocrograms per liter in the reclaimed effluent compared to 3 to 7 micrograms per liter measured in the house water.

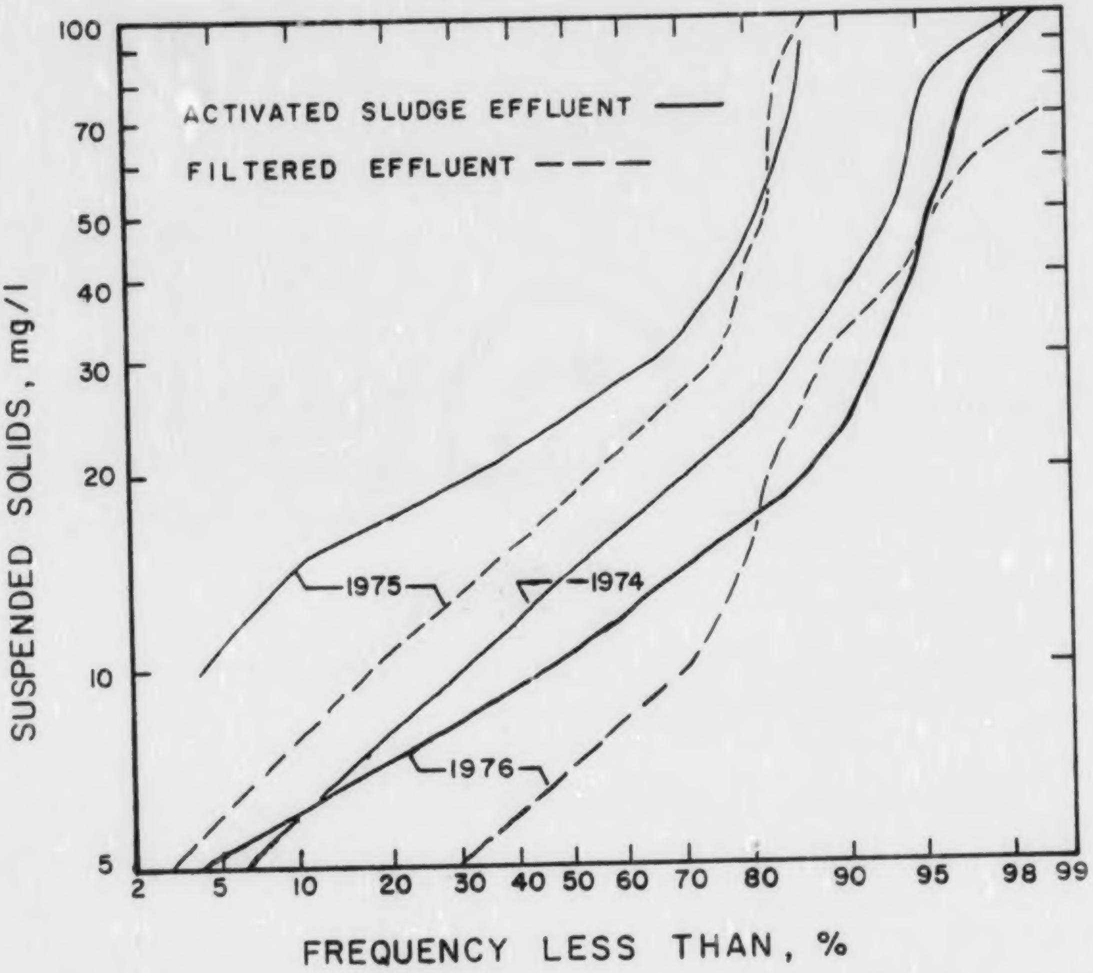

Figure 3. Suspended Solids in Biological and Filtered Effluents during Pear and Peach Processing - 1974, 1975, 1976 Seasons. Snokist Growers Cannery.

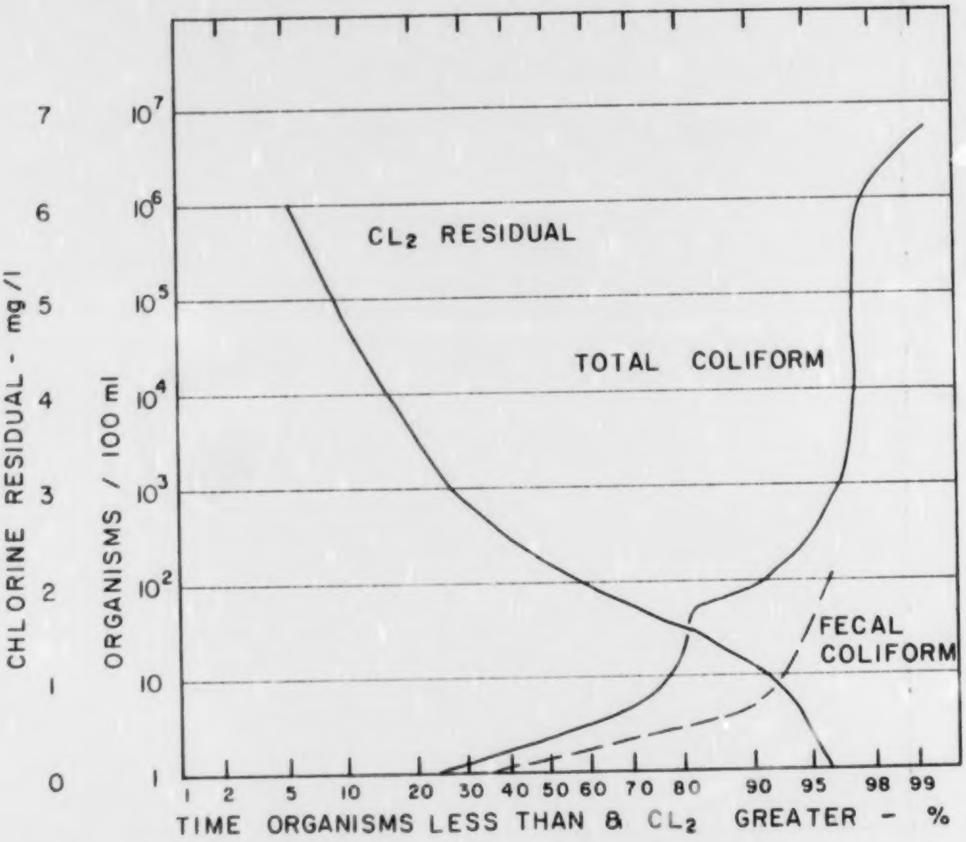

Figure 4. Chlorine Residual and Total and Fecal Coliform in Reclaimed Effluent. Snokist Growers Cannery 1976 Processing Season.

Trial Uses of Reclaimed Water

The reclaimed water with house steam and with steam generated from the reclaimed water was tested for equipment cleaning against house water with house steam. No differences could be detected in equipment sanitation.

The reclaimed water was used for initial product cleaning and conveying. Its use in the peach bin dump tank for 3 days was compared to 3 days with house water. Results are shown on Figure 5. Figure 6 shows the results of using the reclaimed and house water in the apple dump and initial conveying area. No differences in product quality resulted from use of the reclaimed water.

The reclaimed effluent was of equal quality in both hardness and silica to the house water for consideration as a boiler feed source. It was used in a portable steam generator to provide steam for comparison with house steam for cleaning, exhausting, cooking and blanching. As noted above no differences in cleaning were detected. Pears exhausted with reclaimed water steam could not be significantly distinguished from the house steam exhausted controls. Apple sauce cooked with house and reclaimed water steam and apple slices blanched with the two steams were different but differences were judged to result from varying degrees of carmelization due to heat and time differences in the batch processes used. The normal continuous processes could not be used with the portable steam generator.

The reclaimed water was used for trial runs of direct contact container cooling. During the 1975 season about 1200 cans were cooled in reclaimed water and an equal number of controls retained. One hundred cans from each cooling water were stored at 30° C for 3 months. No differences were apparent on opening. One thousand cans from each cooling water were stored at 18° C for a year. No failures occurred in either set. During 1976 over 3000 cans were cooled in each the reclaimed and house water. Approximately 100 of each were stored at 35° C for 6 months with no failures and no discernable differences. The additional 3000 from each cooling water have been stored 6 months at about 18° C with no failures noted.

DISCUSSION

The process effluent being treated and reclaimed by Snokist Growers Cannery appears to be suitable for use in several areas of the cannery. The uses include initial product dumping and conveying, washdown of floors, gutters and equipment, boiler feed and direct contact container cooling. The greatest beneficial use at Snokist appears to be for container cooling with the cooling water subsequently used for floor and gutter wash. A 50% reduction in wastewater discharge and pollutant emission is anticipated when this use is implemented.

Cost of the filter system, chlorination system, pumps and piping were approximately $300,000. Operation and maintenance costs are expected to be about $5,000 per year. Approximately 90 million gallons of effluent may be reclaimed and reused during a typical processing season for which the allocated cost is estimated at about $0.35 per thousand gallons including

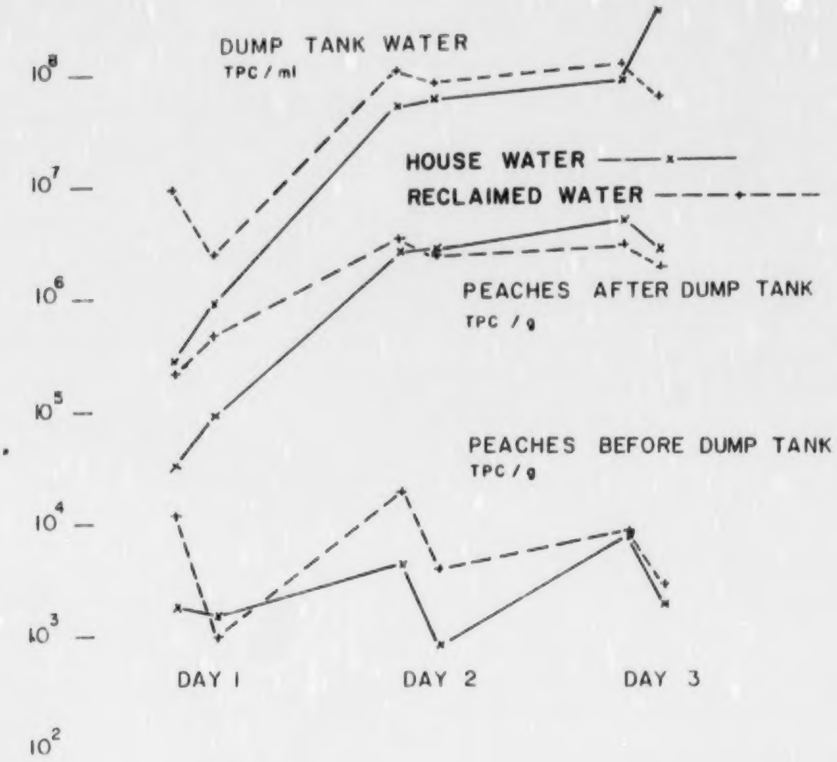

Figure 5. Total Plate Count in Dump Tank and on Fruit Using Reclaimed and House Water - Peaches.

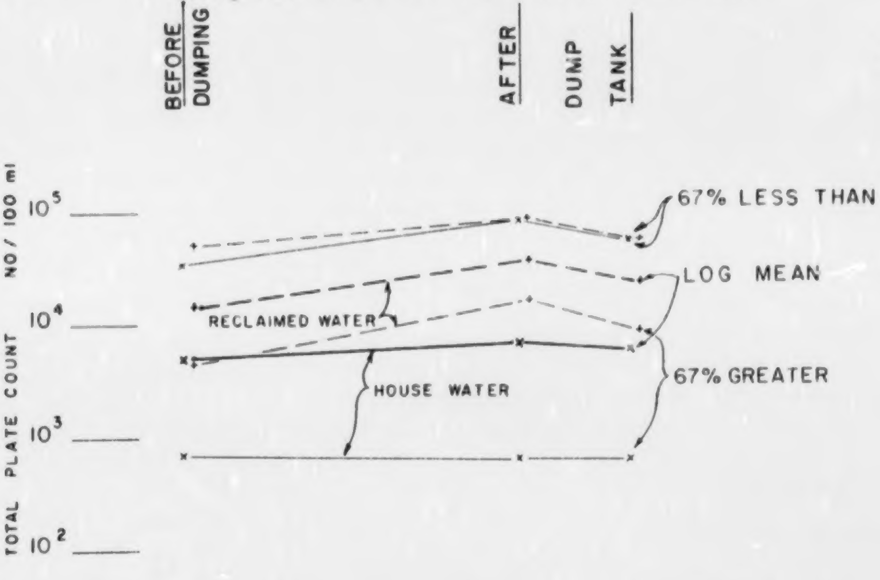

Figure 6. Total Plate Count on Fruit Using Reclaimed and House Water in Bin Dump Tank - Apples. Snokist Growers Cannery - 1976 Processing Season.

amortization. This is not a competitive price with other supply sources in the Yakima area but the value for meeting 1983 effluent standards is added justification for considering this type of system in the future.

SUMMARY

The results of a two-year study of reclamation and reuse of treated process wastewater at Snokist Growers Cannery show the reclaimed water quality to be suitable for use in the following areas of the fruit cannery:

1) Initial fruit wash and conveying.
2) Washdown of fruit peeling and conveying equipment.
3) Steam generation boiler feed.
4) Floor and gutter wash.
5) Direct contact container cooling.

The consistent suitability for use in these areas is contingent upon a well disinfected, low suspended solids product from the biological effluent polishing system which consists of mixed media filtration and chlorination. The polishing system performance is, however, highly dependant on performance of the biological treatment system (activated sludge) in producing a low suspended solids effluent.

Reclaimed water reuse during the 1976 process season resulted in approximately 35% reduction in wastewater discharged. Projections for full scale cooling use indicate a 50% or greater effluent reduction will be achieved.

REFERENCES

1. Aerobic Treatment of Fruit Processing Wastes. FWQA Report DAST-8. Snokist Growers, Yakima, Washington (1969)

2. Esvelt, L. A. and H. H. Hart. "Treatment of Fruit Processing Waste by Aeration," JWPCF, 42:1305 (1970).

3. Esvelt, L. A. "Aerobic Treatment of Liquid Fruit Processing Wastes," Proc. First National Symposium on Food Processing Wastes. EPA, PNWL, Corvallis, OR (1970).

CONTROL OF ODORS FROM AN ANAEROBIC LAGOON TREATING MEAT PACKING WASTES

by

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and W. J. Wells, Jr.****

INTRODUCTION

The warm, highly concentrated wastes from a meat packing operation are uniquely suited to the use of anaerobic lagoons to provide a high degree of pretreatment prior to final aerobic treatment. The advantages of anaerobic lagoons include minimum design removal efficiencies of BOD, grease, and suspended solids of 80%. The anaerobic process has minimum capital and operating costs, is simple to operate, mechanical equipment is not necessary, and the treatment processes can withstand the shock loadings common in the food processing industry.

One major disadvantage associated with the anaerobic lagoons is the odors that result from such a process. This problem has resulted in many companies seeking other treatment alternatives at considerable penalties in capital and annual operating costs.

The cause of these odors and a successful method of eliminating the problem is the subject of this paper. Also discussed is a conceptual process for recovering a significant amount of wasted energy by utilizing the heating value of the methane generated by the anaerobic process. The financial incentive for using the anaerobic process as opposed to a completely aerobic system for the treatment of meat packing wastes in a proposed packing plant is also presented.

BACKGROUND

The anaerobic digestion process utilizes bacteria which function in the absence of free oxygen to break down organic waste. The waste material is converted through a number of intermediate products to water, gases and solids of lesser molecular weight. The bacteria use bound oxygen to survive and obtain it from organic compounds, water and oxides of nitrogen and sulfur. The gases produced are mainly methane and carbon dioxide which are odorless. However, reduction of sulfur-containing organic matter and sulfates produce organic sulfides, occasionally disulfides in the C_1-C_6 range, and hydrogen sulfide (1).

Hydrogen sulfide (H_2S) is usually the major cause of objectionable odor from the anaerobic process. It has an odor characteristic of rotten eggs,

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which can be detected at very low concentrations of between 1.0×10^{-5} and 1.0×10^{-4} mg/l in water (2) and 4.7×10^{-4} ppm in air (3). Hydrogen sulfide is also a toxic gas, having a threshold limit of 10 ppm for industrial exposure with concentration of 20 - 150 ppm causing eye irritation. A thirty minute exposure to 500 ppm of hydrogen sulfide can result in dizziness, headache, staggering, loss of consciousness, diarrhea, bronchitis and broncho-pneumonia. Finally, exposure to 800 -1000 ppm can be fatal in 30 minutes or less (4). The toxicity of the gas is of concern in confined structures such as sewer or wetwells, but its odor is of primary importance to the utilization of lagoons.

The reduction of sulfate to sulfide under anaerobic conditions is well established. Sulfate is considered to be the source of almost all the sulfide in the anaerobic lagoon. Part of the sulfide produced will combine with metal ions, such as iron, and become insoluble. Most of the sulfide usually remains soluble as hydrogen sulfide and, at the near neutral pH in the anaerobic lagoons, partially dissociates into hydrogen and bisulfide ions. The sulfide remaining as H_2S in solution will escape into the air until its partial pressure is in equilibrium with the H_2S in solution. Thus, the odor of hydrogen sulfide from an anaerobic lagoon is proportional to the sulfate in the waste water treated. The source of sulfates is the water supply. Sulfate concentrations are not thought to be increased by the meat packing operations. From experience, the meat industry and state regulatory agencies have not usually considered using anaerobic lagoons when the sulfate in the water supply exceeded 200 mg/l, and some are reluctant with concentrations over 100 mg/l.

Two laboratory investigations (5) (6) have reported on the theory of sulfide production and have developed basic information under controlled conditions. Lawrence, et al., combine the dissociation and gas equilibrium equations to form equation 1. that can be used to calculate the ratio of concentrations of soluble sulfides in the water to hydrogen sulfide in the gas.

$$1. \quad \frac{[TSS]}{[H_2S_g]} = \alpha\left(\frac{1 + K_1}{[H^+]}\right)$$

Where TSS is $HS^- + H_2S$ in water,

H_2S_g is hydrogen sulfide in gas,

H^+ is hydrogen ion concentration in water,

α is the absorption constant, and

K_1 is the ionization constant.

The Handbook of Chemistry and Physics has values on α and K_1, at various temperatures. Data collected during the investigation gave somewhat higher ratios of (TSS/H_2S_g) than was calculated by the equation. From the experimental data, the ratio would be expected to vary from 4 to 8 at the normal pH of digesters.

They operated several 20 liter anaerobic digesters to which known amounts of sulfate were added to the influent. When 200 and 400 mg/l of SO_4-S was added, the equilibrium soluble sulfide concentrations were 32 mg/l as S and 78 mg/l as S, respectively. For the digester receiving 400 mg/l SO_4-S, a figure in the Lawrence paper shows the sulfides in the gas to be 10 mg/l as S.

Lawrence, et al., conclude that the concentration of hydrogen sulfide in the digester is related to the concentration of hydrogen sulfide and sulfide percursers (sulfates) entering with the waste minus the quantity of hydrogen sulfides expelled with the gas and that the quantity of sulfides in the gas is related to the solubility of hydrogen sulfide, the pH, and the total amount of gases produced. They also determined that up to 400 mg/l of sulfide can be precipitated by added iron compounds with no adverse effect on the anaerobic treatment process. Precipitation of the sulfides eliminates the hydrogen sulfide odor.

Gloyna and Espino utilized 430 liter pilot units in developing equation 2. to calculate the sulfide production in lagoons.

$$2. \quad S^{=} = K\,(SO_4^{=})$$

Where $S^{=}$ is 24 hour average sulfide concentration in the lagoon, $SO_4^{=}$ is the concentration of sulfate ion in the influent, and K was determined by the investigation to be:

$$K = .055 + .00012\ (\text{lb.BOD/ac}) + .0016\ (\text{detention in days})$$

The test data is reported in Table 1.

TABLE 1. RESULTS FROM LABORATORY LAGOON STUDIES

Test No.	BOD lb/AC/day	SO_4 mg/l	Temp °C	Detention days	Sulfide mg/l
1	136	23	25	30	0.432
2	68	23	23	30	0.500
3	136	23	26	15	1.12
4	136	206	23	30	4.29
5	68	200	25	15	6.36
6	136	400	26	30	8.76

These two investigations indicate the concentration of hydrogen sulfide in solution in an anaerobic lagoon will be between 2 and 5 percent of the SO_4 concentration in the untreated wastewater. Using the established ratio of soluble sulfide to sulfide in the gas the calculated hydrogen sulfide concentration escaping to the atmosphere will be nearly one percent of the SO_4 concentration in the wastewater.

Since the threshold odor in air is 10^{-4} ppm for hydrogen sulfide, the odor of hydrogen sulfide would be present with sulfates at 10^{-2} mg/l in the water supply. Experience has shown that a concentration of sulfates up to 100 mg/l in the water produces odors that are accepted, thus dispersion of the hydrogen sulfide in the atmosphere is a major factor in odor control.

Models for dispersion of odors were found in the literature (7) (8) (9). A simplified model to determine maximum horizontal distance of odor travel is shown in equation 3..

$$3. \quad \frac{C}{Co} = k\left(\frac{X}{Do}\right)^{n}$$

Where Co is initial odor concentration

C is odor concentration at X

X is horizontal distance from the source, and

Do is diameter of the odor source.

When using constants (k = 1, n = -1.5) developed by Shirazi, et al. (9) the necessary distance to reach a threshold odor was 5 miles from an anaerobic lagoon receiving 388 mg/l SO_4. (The design of such a lagoon is proposed in this paper). An attempt to verify these constants with odor data collected by Minor and Stark (10) was unsuccessful. However, these facts agree with experience that odor control by dispersion of H_2S from anaerobic lagoons treating high sulfate wastewaters is impracticable and perhaps unpredictable.

CASE HISTORIES

Two of the first cases of hydrogen sulfide odor problems with an anaerobic lagoon treating meatpacking wastes occurred at Storm Lake and Harlan, Iowa. In both cases, the odors were sufficient to initiate nuisance complaints. Sulfates in both water supplies were quite high; ranging from 75 to 1560 mg/l at Harlan and from 126 to 690 mg/l at Storm Lake. In both cases, the meatpackers switched to another source of water with lower sulfate concentrations to reduce the odor problem.

An anaerobic lagoon was constructed in 1965 to treat packinghouse wastewater near Cherokee, Iowa. The well water analysis showed an average of 90 mg/l of sulfate. On a winter day, minor odor was detected by one of the authors 20 feet downward from the lagoon. However, there were signs of metal deterioration, typical of hydrogen sulfide corrosion, on the doors of the control building and on a nearby cyclone fence. Occasional odors have been detected by local citizens, but operation or design changes have not been necessary to control odors.

In 1970 the City of Spencer, Iowa, had an anaerobic lagoon designed for treatment of municipal wastewater consisting of about 90 percent meatpacking wastes.

The meatpacker had his own wells, but they were in the same aquifer as the municipal wells, which had sulfate concentrations of 1030 to 1050 mg/l. Because of objections by 108 local residents, odor control was incorporated in the lagoon design. The engineered design included: (1) Limiting the meatpacking wastewater to sulfate concentration of less than 200 mg/l by developing another ground water supply. (2) Maintaining a scum layer on the lagoon to reduce the release of H_2S from the lagoon surface. (3) Using submerged inlets and outlets on the anaerobic lagoon to reduce H_2S release. (4) Maintaining a 7.0 pH to reduce release of H_2S by reducing the partial pressure of the gas. (5) Putting the effluent through a degasifier to remove the H_2S and passing the gas through an ozone chamber to oxidize the H_2S. However, because of the odor potential and later imposed ammonia limits, the anaerobic lagoon was not constructed.

Anaerobic lagoons are used by a meatpacker in Denison, Iowa. The sulfate concentration in the anaerobic lagoon influent and effluent averaged 332, and 39 mg/l, respectively. Hydrogen sulfide in the anaerobic lagoon effluent averaged 4.6 mg/l. The lagoons were covered with a thick layer of scum, but the H_2S odor was strong at the overflow weir and at a small tank in which the lagoon effluent was aerated. The treatment plant operator described the odor as a bad situation and aromatic chemicals were used to mask the odors.

In Texas, two anaerobic lagoons treating meatpacking wastes are known to have significant odor problems (11). One packer obtains water from the city of Sweetwater with a measured sulfate content of 218 mg/l. Personnel from the Extension Service made three odor intensity measurements on the downwind side of the lagoon which required 31 (D_t) dilution to reach a threshold odor. The other packer in Maverick County used water from the Rio Grande River which had a sulfate concentration of 190 mg/l. Odor measurements made downwind were 31 D_t alongside the lagoon and 2 D_t at 3/4 of a mile from the lagoon. The packer in Maverick County ceased operation due to financial problems and odor control became unnecessary. The Extension Service recommended to the other packer conversion of the anaerobic lagoon to an aerated lagoon.

In Moerewa, New Zealand, anaerobic lagoons are used to treat settled meatpacking waste (12). The main criticism of the lagoon was reported as the odor of hydrogen sulfide associated with the gases. The sulfate concentration of the wastewater is not given, but an analyses of the evolved gas was: hydrogen sulfide at 0.4%, carbon dioxide at 7.0%, methane at 85.0%, oxygen at 0.6% and nitrogen and others at 7.0%. A record of hydrogen sulfide in the air close to the lagoons was kept for 8 months. The highest concentration was an isolated occurrence of 0.99 mg/l, but of the total number of readings at two-hour intervals, 1897 were nil and 389 were positive with an average concentration of 0.02 mg/l.

The odor control at Moerewa consisted of maintaining a scum cover on the lagoon. The effectiveness of the cover in reducing the escape of hydrogen sulfide was established by air samples taken four inches above the water or scum cover. The concentration of hydrogen sulfide above the scum averaged 0.35 mg/l, compared to the concentrations ranging from 2.0 to 15.0 mg/l over the scum free areas.

In 1973, the city of Greeley, Colorado, initiated operation of anaerobic lagoons which received 95% of their wastewater flow from a large meatpacker. The water supply at the packing plant contained 700 to 800 mg/l of sulfates (13). A severe odor problem occurred at the anaerobic lagoon. After one year's operation, city water was extended to the packer. The sulfate concentration in the city water was about 40 mg/l. Six months after the lower sulfate water was used, odor continued to be a problem. In July 1975, the State of Colorado Air Pollution Control Agency found the facility in violation of air quality standards for odors and subsequently issued a cease and desist order. These air quality standards have a maximum limit for odor at the property line of 15 D_t. Five other states have similar standards (8).

Several new operation schemes were undertaken to control the odor. To build up a heavy scum layer on the surface, all of the plant flow was routed to anaerobic lagoon No. 3. The addition of straw and grease to aid in developing a cover was planned as a second step. Such a cover was expected to reduce odor emissions from the lagoon. After the scum completely covered the surface, measured odors were below the air quality standards for a two month period.

However, due to an excess build-up of solids in lagoon No. 3, another lagoon (No. 1) was put into operation on December 17, 1975, and odor levels in excess of the air quality standards reoccurred. Beginning on January 23, the primary treatment process at the packing plant was bypassed to increase the grease level and more rapidly form a cover on lagoon No. 1. On March 1, the addition of 10 mg/l of chlorine to the packing plant effluent was initiated to reduce sulfide odors at the lagoon inlet. In the 30 days after the initiation of chlorination, the scum layer went from 35 to 40 percent cover on lagoon No. 1 to a 99% cover. High winds sometimes broke up the scum layer and temporarily reduced the percent of surface area covered. The wastewater became anaerobic in 32,500 feet of force main between the packing plant and the lagoons. Measurement of the hydrogen sulfide concentration in the wastewater showed up to a 50 mg/l decrease at the inlet to the lagoon when chlorination was practiced. The build-up of the cover and corresponding decrease in the odor dilutions reading are shown in Table 2.

TABLE 2. PERCENT OF SURFACE AREA COVERED (14)

Date	Lagoon No. 1	Lagoon No. 3	D_t
March 30	--	--	--
March 29	--	--	--
March 26	99	100	0
March 25*	99	100	7
March 24	99	100	0
March 22	99	100	0
March 19	60**	60**	7
March 18*	95	100	7
March 17	98	100	0
March 11	85**	100**	7

TABLE 2. PERCENT OF SURFACE AREA COVERED (14) (Cont.)

Date	Lagoon No. 1	Lagoon No. 3	D_t
March 9*	95	100	0
March 8	95	100	7
March 3	35	100	0
March 2	45	100	15
March 1*	40	100	15
February 25*	40	100	0
February 19*	20	100	15
February 16	5**	60**	15
February 13	35	100	15
February 4	10	100	31
February 3*	10	100	170
February 2	10	100	--
January 29*	5	100	--
January 28	5	100	--
January 26	5	100	--

* Odor readings by State officials

** Days of high winds

The overall effectiveness of the scum cover in reducing odor emissions is summarized in Figure 1. Only those odor measurements made by the State Agency personnel are shown on the figure.

During March 1975, a series of sulfate measurements was made by the city on the packing plant effluent and the influent to the treatment plant and are shown in Table 3. Additional sulfate measurements on the packing plant effluent averaged 95 and 90 mg/l in April and May, respectively.

TABLE 3. SULFATE CONCENTRATIONS

Date	Packing Plant Effluent (mg/l)	Treatment Plant Influent (mg/l)
March 2	48	--
March 3	110	71
March 4	45	47
March 5	110	220
March 8	150	80
March 9	--	120
March 15	121	--
March 16	--	120
March 19	66	140
March 22	160	--

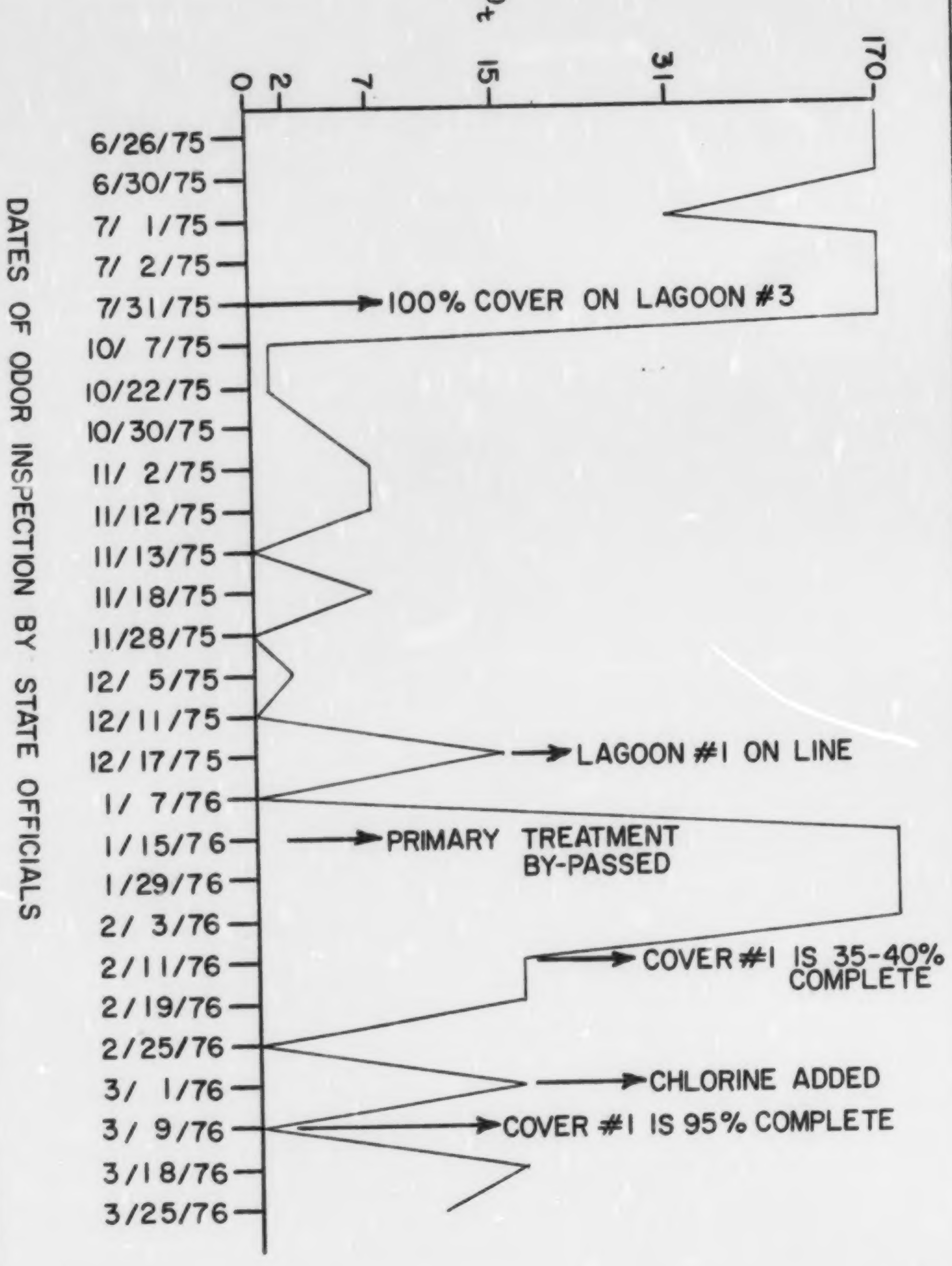

FIGURE 1. ODOR LEVELS WITH VARYING OPERATION (8).

TABLE 3. SULFATE CONCENTRATIONS (Cont.)

Date	Packing Plant Effluent (mg/l)	Treatment Plant Influent (mg/l)
March 23	--	205
March 25	88	80
Average	100	120

The city rechecked its testing procedures and reagents for the sulfate test and found no discrepancies. Tests on city domestic water showed SO_4 concentrations in the range of 40 - 60 mg/l. An increase of about 50 mg/l of sulfates by the meat packing process is shown by this data. This increase is contrary to the commonly accepted belief that sulfate concentrations are not increased in the meat packing process.

An anaerobic lagoon was used to treat meatpacking wastewater near Ada, Oklahoma. The water supply had a sulfate concentration of 4.0 mg/l. During a two-year period, one of the authors inspected the lagoon over 200 times and detected septic odors within a few feet of the lagoon, but the odor of H_2S was not detected. The lagoon did not have a scum cover and bubbles at the surface showed considerable gas production. The lack of odor was attributed to the low sulfate concentration in the water (15).

DESIGN CONSIDERATIONS

A study of acceptable methods of controlling anaerobic lagoon odors was initiated in the course of the design of a new meat packing facility to be located in Southwestern Arizona. In order to enable the reader to evaluate the potential of the concepts presented in this paper, the results of that study are discussed in detail in the remaining pages of this article.

In the proposed location of the meat packing plant, ground water supplies were limited and of such poor quality that it was concluded that water would have to be obtained elsewhere.

The only other available source of water was the irrigation canal that bordered the property. Discussions with the Bureau of Reclamation and the local Water and Drainage Districts indicated that approval would be granted for withdrawing the necessary water.

A typical analysis of the water is given in Table 4. Although the water was somewhat high in salinity, it would be acceptable for potable use after suspended solids removal and chlorination. Previous experience had shown, however, that the high sulfates (388 mg/l) would produce unacceptably high odor emissions from the anaerobic lagoons.

TABLE 4. IRRIGATION WATER ANALYSIS

Constituent	Concentration mg/l
Silica	9
Calcium	91
Magnesium	32
Sodium	126
Potassium	6
Bicarbonate	172
Carbonate	0
Sulfate	388
Chloride	107
Fluoride	0.5
Nitrate	Nil
Dissolved Solids	796
Hardners as $CaCO_3$	360
Non-carbonate Hardners as $CaCO_3$	218
Specific Conductance mmhos	1.240

The meatpacking company retained a consulting firm to study the problem and make recommendations. In particular, the consultant was given two assignments:

1) Develop the capital and operating costs of a completely aerobic waste treatment system and compare those costs with the capital and operating costs of an anaerobic lagoon system followed by a minimum of aerobic treatment.

2) Explore the various alternatives for collecting and treating the gases generated by the anaerobic lagoon so that acceptable odor emission would result. In particular, the anaerobic lagoon cover developed for the Wilson & Co. plant at Monmouth, Illinois was to be evaluated as a potential candidate for the Arizona lagoon.

The proposed plant location also dictated two other significant design parameters. First, the final disposal of the waste water would be cropland irrigation. There was no stream available to accept treated wastes. The State required treatment of the waste prior to irrigation to a level that produced a maximum BOD_5 of 100 mg/l. Since the crops could utilize the nitrogen in the ammonical form, nitrification was not a problem. The second factor dictated by the proposed site was that aerobic lagoons for final treatment of the waste were precluded by the soil conditions on the site. The soil was all sand and cost estimate comparisons of sealing the large area lagoons to meet acceptable ex-filtration rates versus the cost of small area aeration basins indicated that extended aeration would be the cheaper alternative.

The proposed plant was to be capable of slaughtering 2880 head of beef per day and breaking 2000 beef carcasses per day into boxed beef. Drawing up the experience of similar plants, the raw and treated wastes characteristics were formulated. Their design values are shown in Table 5.

TABLE 5. WASTE CHARACTERISTICS

	Raw Wastes	Treated Wastes
Flow - MGD	2.88	2.88
BOD mg/l	1500	60
SS mg/l	1200	80
Grease mg/l	900	10
Total K-N mg/l	200	160

A summary of the study to evaluate the treatment alternative and the comparisons of the candidates for a lagoon cover is given in the following paragraphs.

Completely Aerobic System

A schematic of the proposed completely aerobic system is given in Figure 2. The first stage aerobic treatment was to be accomplished with two parallel fixed media towers using redwood media. The influent BOD_5, estimated at 1500 mg/l, would be reduced by 65% in the towers. Recirculation around the towers would maintain an adequate wetting rate to enhance treatment efficiency.

The second stage aerobic treatment chosen was two parallel aeration basins each containing 250 hp of either slow speed, fixed platform aerators, or a dispersed air system using static tube diffusers.

The final clarifiers were used to settle the wastes. The settled solids were returned to the inlet of the redwood towers so that the fixed media towers would operate in the activated biological media mode. Provisions were also made to allow sludge return to the extended aeration basin in order to maintain the MLSS at desirable levels. Approximately 0.2 MGD of sludge would be wasted to an aerated sludge holding tank with two days holding capacity.

Approximately 30 acres of storage ponds to provide 20 days of storage would be provided after the final clarifiers. To avoid ground water contamination, the lagoons would be sealed.

Effluent from the ponds would be utilized for irrigation.

The aerated sludge from the sludge holding tanks would be pumped directly to a separate irrigation system.

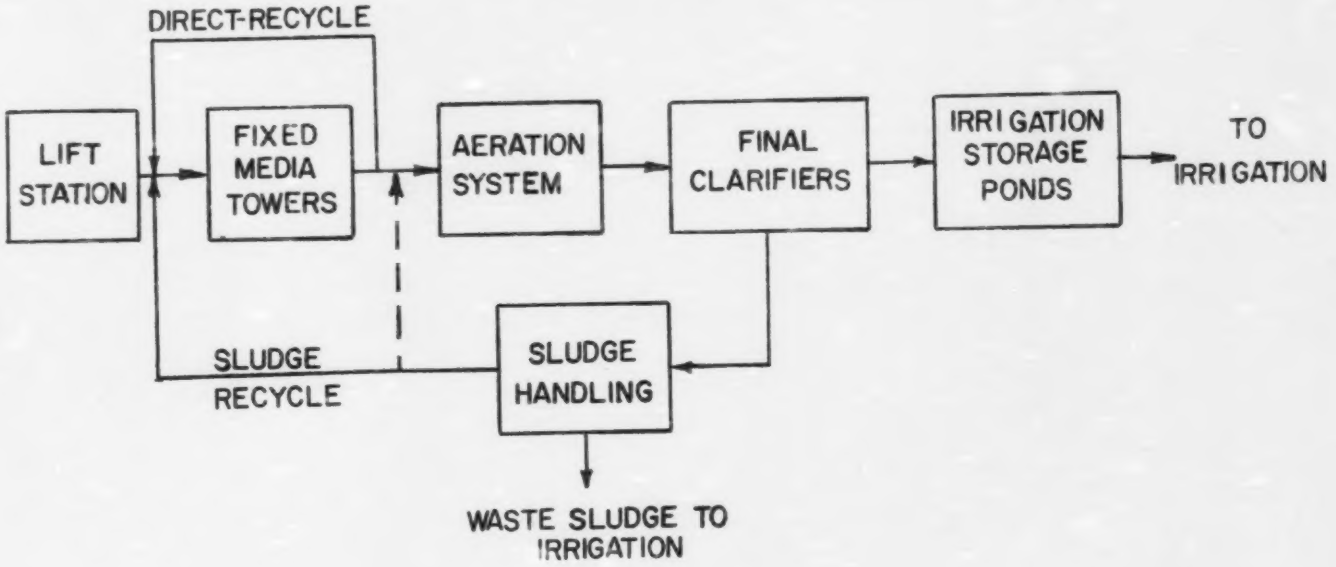
DIRECT-RECYCLE
LIFT STATION
FIXED MEDIA TOWERS
AERATION SYSTEM
FINAL CLARIFIERS
IRRIGATION STORAGE PONDS
TO IRRIGATION
SLUDGE RECYCLE
SLUDGE HANDLING
WASTE SLUDGE TO IRRIGATION

FIGURE 2.
COMPLETELY AEROBIC SYSTEM SCHEMATIC.

Anaerobic/Aerobic System

In order to utilize anaerobic lagoons in this application it would be necessary to have an effective gas collection system to prevent objectionable odorous emissions.

A study was made of the available covers that could be used in this application. A cost summary of this study is shown in Table 6.

TABLE 6. COMPARATIVE ANAEROBIC LAGOON COVER COSTS

Type	Basin Size	No. Basins	Est. Cover Cost
Fiberglass Arch	50' x 300'	9	$1,419,000
Precast Concrete Double Tees	50' x 300'	9	600,000
Floating Fiberglass	130' dia.	5	730,000
Floating Flexible Membrane	200' x 300'	2	253,000

The preceeding costs are for the cover only. The cost of concrete, earthwork, pipe, fittings and protective coatings is not included. Obviously, the flexible membrane would be the cover of choice. A flow sheet of the combination anaerobic/aerobic system is shown on Figure 3.

In order to minimize the cover cost, the design of the anaerobic lagoons was given careful consideration. The loadings were set on the high side of normal design criteria - 17.5# BOD/1000 ft^3. The water depth was to be maintained at 20 feet rather than the more conventional 15 feet. Finally, the slopes above water level were maintained at 4:1, while the dikes below water level were cut to 1:1 slope.

From the anaerobic lagoon, the waste was to be treated aerobically in two aeration basins operating in the completely mixed activated sludge mode. Sludge wasting from the two final clarifiers would be to the anaerobic lagoons. Because of the high anaerobic lagoon BOD removal efficiency (80%), the aerator horsepower requirements would be 400 horsepower rather than the 500 horsepower required in the completely aerobic system.

The lined storage ponds prior to irrigation would be identical to that discussed in the completely aerobic system.

Cost Comparison

The estimated costs for the two alternative systems are shown in Table 7.

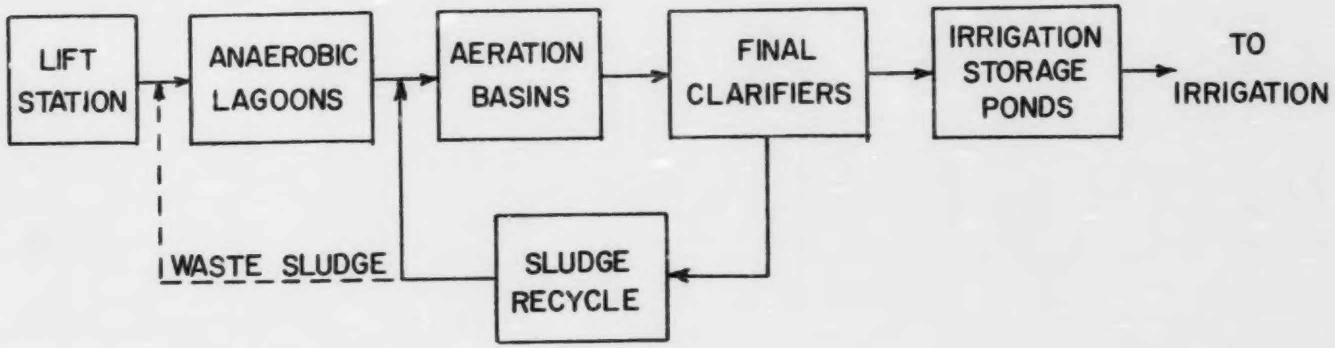
LIFT STATION
ANAEROBIC LAGOONS
AERATION BASINS
FINAL CLARIFIERS
IRRIGATION STORAGE PONDS
TO IRRIGATION
WASTE SLUDGE
SLUDGE RECYCLE

FIGURE 3

ANAEROBIC / AEROBIC SYSTEM SCHEMATIC.

TABLE 7. CAPITAL COST COMPARISONS--2.88 MGD PLANT

	Completely Aerobic System	Anaerobic/Aerobic System
First Stage Aeration	$1,266,000	-0-
Anaerobic Lagoons	-0-	$ 194,000
Second Stage Aeration	779,000	688,000
Sludge Handling Facilities	375,000	83,000
Irrigation Storage Ponds - 30 ac. lined	314,000	314,000
Subtotal	$2,734,000	$1,279,000
Anaerobic Lagoon Cover w/Burner	-0-	369,000
Total Cost	$2,734,000	$1,648,000

From the preceeding table it can be seen that the covered anaerobic lagoons followed by a mechanical aerobic system would result in an estimated capital cost savings of over $1,000,000 for a 2.88 MGD plant.

In addition, there would be an appreciable savings in annual operating cost as shown in Table 8.

TABLE 8. ESTIMATED ANNUAL OPERATING COST COMPARISONS

	Completely Aerobic System	Anaerobic/Aerobic System
Power (2.65¢/KWH)	$155,000	$ 82,000
Labor	22,000	22,000
Maintenance	19,000	9,000
Total	$196,000	$113,000

Anaerobic Lagoon Cover Construction Details

Many attempts to construct a successful lagoon cover have been made over the years and most of them have been notable for their lack of success. For one thing, earlier covers lacked the ability to withstand u.v. degradation. Lack of permanent bonding of seams was also a common failing. Another weakness common to earlier systems was the lack of an adequate gas removal system. This resulted in large pockets of gas producing bubbles under the film. One system that was inspected had gas bubbles 10 feet high and 100 feet in diameter.

The system at Monmouth, Illinois, that was supplied by Globe Linings, Long Beach, California, and designed and specified by Messmair, Stanley and Associates of Rock Island, Illinois, appears to have met and solved these problems. The significant design and construction details are discussed below.

The cover material is five ply, 45 mil composite constructed of two nylon reinforcing screens bonded to three sheets of DuPont Hypalon 45 synthetic rubber. The estimated cost of the anaerobic lagoon cover is detailed in Table 9.

Gas removal is of prime importance. To conduct the gases and to act as a cover support, four inch by twelve inch styrofoam logs were inserted in a factory-sealed envelope in the liner. A sketch of this concept is shown in Figure 4. The logs were placed across the width of the lagoon on 20 foot centers with one row down the length of the lagoons.

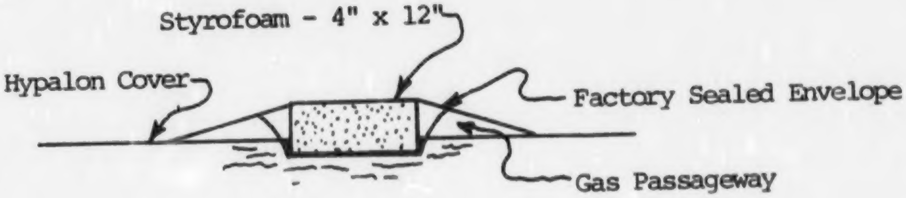

FIGURE 4. CROSS SECTION OF COVER FLOAT SYSTEM

The gas generated by the anaerobic action in the lagoon follows the space between the styrofoam float and the cover out to the edge of the lagoon. It was feared that in time the solids build-up on the lagoon surface would tend to fill up these passageways. To date, this has not occurred. Small bubbles 6 to 12 feet in diameter and 6 to 10 inches high do form, but when the cover is lifted to this point, the gas leaked out through the passageways and the cover subsided back to the surface.

A sketch of the edge construction details is shown in Figure 5. The use of the aluminum hold down plates results in a positive seal holding in the generated gases. The perforated pipe shown in the sketch and a 103 cfm 1 hp blower was used to collect the gases. The blower must run continuously to prevent gas build-up under the cover.

Provided with the system would be an approved gas incineration system for disposal of the gas. A schematic of the gas train is shown in Figure 6.

One other problem encountered was the disposal of accumulated storm water. A portable 3 inch trash pump is used to pump the rain water out of the pockets in the center of the lagoon.

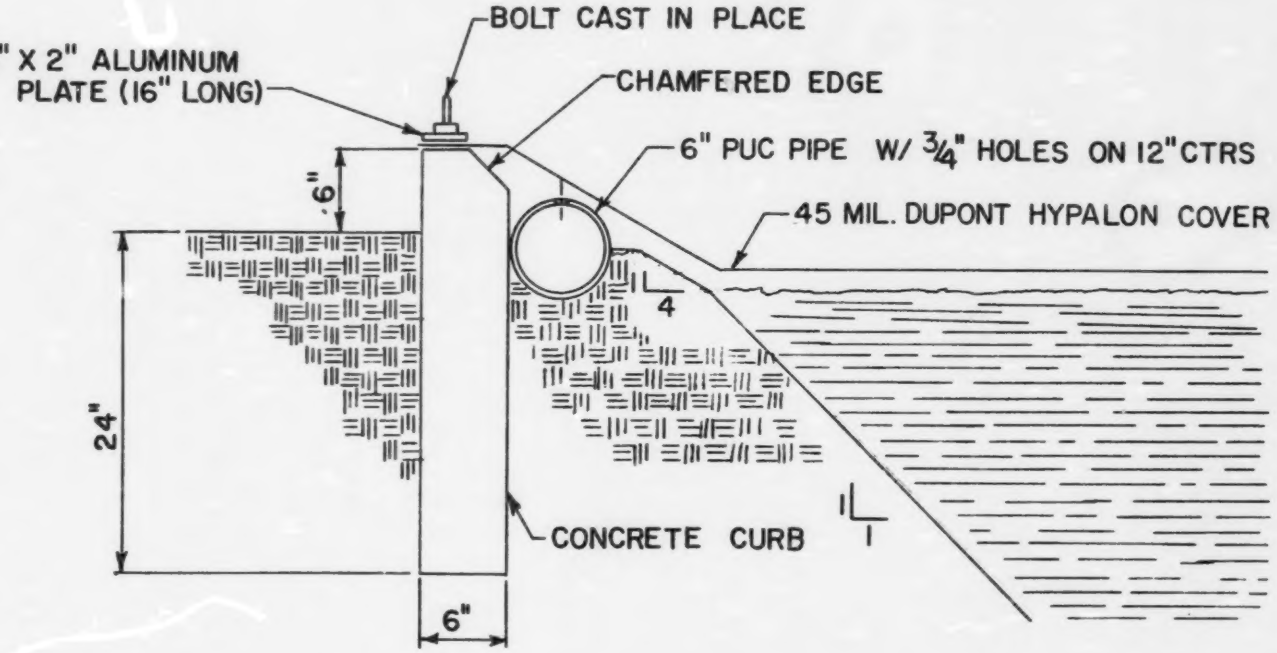
BOLT CAST IN PLACE
1/4" X 2" ALUMINUM PLATE (16" LONG)
CHAMFERED EDGE
6" PUC PIPE W/ 3/4" HOLES ON 12" CTRS
45 MIL. DUPONT HYPALON COVER
6"
24"
4
1
1
CONCRETE CURB
6"

FIGURE 5.
LAGOON COVER INSTALLATION DETAIL.

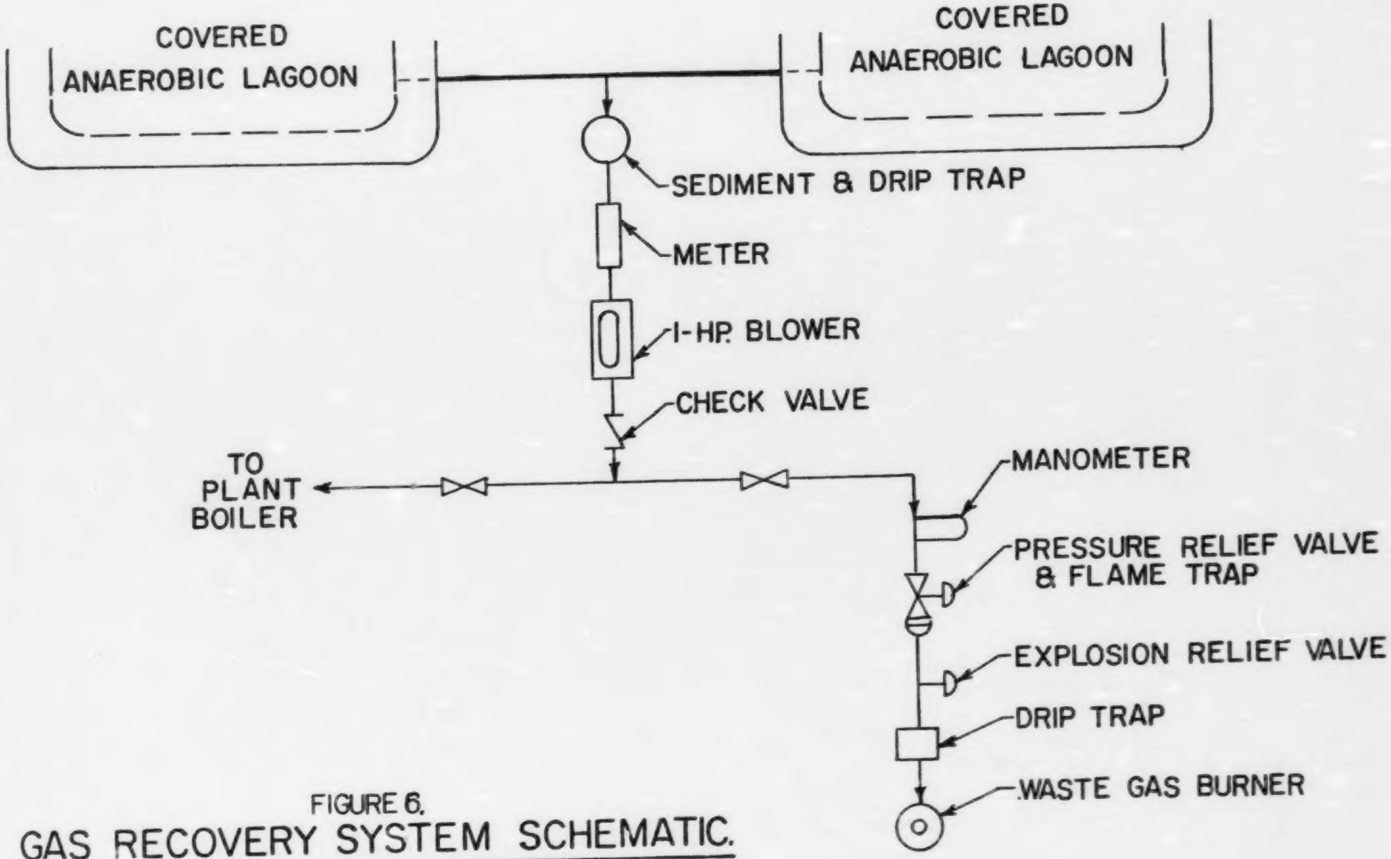
COVERED
ANAEROBIC LAGOON
COVERED
ANAEROBIC LAGOON
SEDIMENT & DRIP TRAP
METER
I-HP. BLOWER
CHECK VALVE
TO
PLANT
BOILER
MANOMETER
PRESSURE RELIEF VALVE
& FLAME TRAP
EXPLOSION RELIEF VALVE
DRIP TRAP
WASTE GAS BURNER

FIGURE 6.
GAS RECOVERY SYSTEM SCHEMATIC.

ENERGY CONSERVATION

In the above discussion, the final disposal of the gas was proposed as incineration. With current energy shortages this viable source of energy should not be wasted. A study was then made of its possible uses.

TABLE 9. ESTIMATED PROJECT COST GAS RECOVERY AND DISPOSAL

Item	Estimated Cost
5 Ply, 45 mil DuPont Hypalon Membrane (126,600 sq. ft.)	$253,200
P.C. Concrete Curb-Wall	12,000
Stainless Steel Anchor Bolts and Nuts	3,900
Aluminum Anchor Plate	4,500
6" Perforated P.V.C. Collection Pipe	10,800
Gas Train Piping, Valves, Blower, Meter & Appurtenances	9,700
Concrete Slab and Gas Equipment Shelter	1,500
Total	$295,600
10% Contingency	29,600
Total Estimated Construction Cost	$325,200
Engineering, Legal and Fiscal	43,600
Total Estimated Project Cost	$368,800

TABLE 10. ANAEROBIC LAGOON GAS ANALYSIS

Methane - Vol. %	65 - 70
Carbon Dioxide - Vol. %	30 - 35
Nitrogen	Trace
Hydrogen	Trace
Hydrogen Sulfide mg/l	16
Estimated Heating Value BTU/ft^3	650
Gas Production - ft^3/#V.S. Destroyed	12 - 18
Anticipated Production ft^3/day	278,000

An expected analysis of the digestor gas is shown in Table 10. From this table it can be calculated that an average of 180 million BTU's per day would be generated by burning this gas. In addition to direct incineration, which would waste this energy, two other methods by which this energy could be utilized were explored.

A Supplement To Fossil Fuels Feeding Existing Boilers

In this alternative various firing schedules were examined such that the waste gases would be stored and used at intervals to fire one or more of the plant's boilers. In addition to the expense involved in constructing and maintaining storage facilities, it soon became obvious that, because of the hydrogen sulfide content of the gas, this was not an acceptable alternative. If the hydrogen sulfide was not removed from the gas a potential for corrosion of the boiler stack existed.

The capital costs of the equipment needed to remove the hydrogen sulfide were estimated to be over $100,000.

Providing a Dedicated Boiler

The next alternative was to provide a separate boiler sized to fire at the rate of gas production. The boiler manufacturers state that if the boiler exhaust was kept above 375°C, corrosion would be no problem. Thus, a conventional carbon steel packaged boiler could be used. The cost of the system was estimated to total $40,000. The estimated annual costs of operating the system are in Table 11.

TABLE 11. HEAT RECOVERY ANNUAL COSTS

Labor	-0-
Utilities	4,000
Maintenance and Upkeep	2,000
Depreciation - 12 years	3,000
Total	9,000

No labor figures were assessed since it was assumed the waste treatment operator could take care of the gas production and collection facilities, and the stationary engineer would handle the boiler operation.

The value of the energy thus utilized was assumed to be the incremental cost of the fossil fuel not consumed as a result of using the gas. These savings are calculated below.

TABLE 12. HEAT RECOVERY SAVINGS

Basis: Coal Cost = $30/ton
Coal Heating Value = 9000 BTU/#
Cost/10^6 BTU = $1.67/$10^6$ BTU
Gas Generation = 278,000 ft^3/day
Heating Value = 650 BTU/#
BTU Recovered @ 85% Eff. = 154 x 10^6 BTU/day

Gross Annual Savings @ 365 days/year = $94,000

The gross annual savings of \$94,000 less the annual cost of \$9000 gives a net savings of \$85,000 per year. This savings is equivalent to a pretax return in investment of 213 percent and it gives a pay back of less than one year.

In the proposed scheme, a 200 HP fire-tube boiler with its own exhaust stack would be provided in the boiler room. The boiler would be provided with a combination boiler to allow he firing of fuel oil of gas production dropped off. (There is no natural gas available for new installation in the proposed location of the plant.)

The lagoon cover itself would be used for gas storage. If the gas production rate exceeded the boiler capacity, the gas incinerator would be fired at intervals to maintain an acceptable balance.

EMISSION CONTROL

The Enforcement Division of EPA, Region IX, was contacted regarding the emissions from a boiler or an incinerator operating on anaerobic gas. The following comments were made:

> "In the solution of any environmental problem, the necessary changes and usage of resources create other environmental stresses. A common case is where a pollutant in one medium (water) is placed on another medium (land). A similar trade-off occurs in this proposed solution for control of odors from anaerobic lagoons. Specifically, burning of the collected gas will result in the conversion of the highly odorous compound, H_2S, to a non-odorous compound SO_2. However, many discharges of SO_2 to the atmosphere are limited by regulations to prevent air pollution. At the proposed location of these facilities in southwestern Arizona, there are regulations limiting the emission of SO_2 from existing boilers which use fossil fuels. The SO_2 regulations currently in effect for southeastern Arizona do not constrain SO_2 emissions from existing boilers using gases produced from anaerobic digestion. However, any new or modified facility would be subject to preconstruction review regulations of the State and local agencies. Such a project could also be subject to EPA new source review regulations depending on its size and location. Since certain portions of southwestern Arizona are not meeting the National Ambient Air Quality Standards for SO_2, any major new source of SO_2 located in such areas would be subject to strict emission limits and offset requirements described in EPA's Interpretive Ruling of December 21, 1976. Furthermore, the State or local agency may impose requirements more restrictive than the minimum required by EPA."

From the above statement it can be seen that prior to an investment decision, the appropriate authorities should be contacted regarding the emissions from incinerating the anaerobic gases. If local conditions warrant, SO_2 removal may be required.

The technology for scrubbing flue gases of SO_2 is well established. One highly effective process would be the use of a bicarbonate scrubber to effect a 90% to 95% removal of the SO_2. The calculated SO_2 emissions from burning the anaerobic gases at a 16 mg/l H_2S concentration would amount to 2.66# SO_2 per million BTU's. A 90 to 95% SO_2 removal efficiency would bring the SO_2 emissions well within new source limitations required for fossil fuel boilers.

Discussions with suppliers of scrubbers to remove 2.66# SO_2 per million BTU's from a 200 H.P. boiler indicated that an installed capital cost of $70,000 and an annual operating cost of $10,000 could be routinely achieved. Land disposal of the waste liquor from the scrubber would be an acceptable disposal technique.

Based on the economic incentive the anaerobic lagoon presents over a mechanical system their added costs should not change the management decision to adopt anaerobic lagoons over a completely aerobic mechanical system.

CONCLUSIONS

Odor problems from anaerobic lagoons treating meat packing wastes are the result of hydrogen sulfide emissions. The hydrogen sulfide escaping to the atmosphere will be nearly 1% of the sulfate concentration in the wastewater.

Anaerobic lagoons which treat wastewaters containing 100 mg/l or more of sulfate need special design and operation for odor control. Design of submerged inlets and outlets, operation to maintain a complete scum cover, chlorination of the raw wastewater prior to pipeline transport when H_2S is produced, and changing to a lower sulfate water supply have been found to reduce odor emissions.

Anaerobic lagoon treatment is both cost effective and energy saving for warm concentrated wastewaters. The major drawback of odor emission, when the wastewater contains high sulfate concentrations, has been controlled with a flexible membrane cover and a positive gas removal system. The floating flexible membrane cover has been shown less expensive than rigid cover systems.

The anaerobic lagoon has been shown economically advantageous over aerobic treatment for meat packing wastewater even with the added cost of a flexible cover and gas removal system.

Although incineration of odorous digestor gas is the common disposal method, these gases can be used economically in a dedicated boiler for the production of steam for process uses and to conserve our fossil fuel resources. This energy conservation system has a one year payout.

REFERENCES

1. Bethea, R. M., "Comparison of Hydrogen Sulfide Analysis Techniques." Journal of Air Pollution Control Association. Vol. 23, No. , p. 710 - 713 (1973).

2. Pomeroy, R. D., and H. Cruse. Hydrogen Sylfide Odor Threshold. Jour. Amer. Water Works Assn. 61(12):677. 1969.

3. Leonardos, G., D. Kendall, and N. Barnard. Odor Threshold Determinations of 53 Odorant Chemicals. Jour. Air Poll. Control Assn. 19(2):91. 1969.

4. American Mutual Insurance Alliance. Handbook of Hazardous Materials. Technical Guide No. 7, Chicago, Illinois, p. 60 (1974).

5. Lawrence, A. W., McCarty, P. L., and Guerin, F. "The Effect of Sulfide on Anaerobic Treatment." Proceedings of 10th Industrial Waste Conference, Purdue University, p. 343 (1964).

6. Gloyna, E. F., and Espino, E. "Sulfide Production in Waste Stabilization Ponds." ASCE Journal of Sanitary Engineering Division, Vol. 95, ND. SA3, p. 607 (1969).

7. Hogstrom, Ulf. Possibilities of Predicting Odor Frequencies in Ambient Air from Sensory and Chemical Analyses at the Source. University of Uppsala, Uppsala, Sweden. 1970.

8. Sweeten, John M. Odor Perception and Measurement. Agricultural Engineering. Texas Agricultural Extension Service, College Station. May 1975.

9. Shirazi, M. A., L. R. Davis, and K. V. Byram. Effects of Ambient Turbulence on Buoyant Jets Discharged Into a Flowing Environment. EPA-National Environmental Research Center, Corvallis, OR. Jan. 1973.

10. Minor, J. Ronald, and Ronald W. Stark. Evaluation of Alternative Approaches to Control of Odors from Feedlots. Idaho Research Foundation Inc. University of Idaho, Moscow, Idaho. Dec. 1975.

11. Personal communication with Dr. John M. Sweeten, Texas Agricultural Extension Service, College Station, Texas.

12. Rand, M. B., and Cooper, D. E. "Development and Operation of a Low Cost Anaerobic Plant for Meat Wastes." Proceedings of Industrial Waste Conference, Purdue University, p. 613 - 638 (1966).

13. Wells, J. W., Wells, P. B., and Alleman, D. D. "Treatment Capabilities of an Extended Aeration System Following Anaerobic Lagoons Treating Meat Packing Waste." Proceedings of Sixth National Symposium on Food Processing Waste. EPA 600/9-76-224.

14. City of Greeley, Colorado. Progress Report No. 2. Corrective Action Plan for Lone Tree Wastewater Treatment Plant. April 1976.

15. Witherow, J. L. "Small Meatpackers Waste Treatment Systems." Proceedings of the 28th Industrial Waste Conference. Purdue University, Lafayette, Indiana (1973).

TOMATO CLEANING, WATER RECYCLE AND MUD DEWATERING **

by

Walter W. Rose*

INTRODUCTION

With the advent of mechanical harvesting, food processors noted an increase in clods of dirt and smear soil coming in with the raw products. The initial response by the industry to this situation was to use more water to insure that the product was adequately cleaned. In recent years there have been several external factors imposed on the industry which now makes it economical to reduce the volume of fresh water and to discharge less pollutants.

With engineering assistance from a consulting firm, Eutek Inc., the National Canners Association put together a project that was addressed to the problem of cleaning tomatoes with less water, the removal of mud from the dump tank and the development of a water recycle system.

BACKGROUND

Results of past work has been reported at previous symposia (1) (2). The major efforts during the previous two years were to demonstrate the use of rotating rubber discs for cleaning and to develop the water recycle system. Prior to the full scale demonstration of low water cleaning by rubber discs, pilot studies had been conducted (3). Studies have also looked into the energy and economic aspects of operating in various modes and results have been reported (4) (5).

Results up to the 1976 season did show that mechanical energy, in the form of soft, rotating rubber discs, effectively clean tomatoes with the use of minimal amounts of water. In addition to the wiping of surface dirt from the tomatoes, the spinning discs also removed a significant number of adhering stems. Physical and chemical treatment was applied to the dump

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tank water and a major portion of the water was recycled back to the dump tank. Soil could be separated from the water and removed from a thickener tank.

The major objectives of the 1976 season were to evaluate the cleaning of tomatoes by a machine of different design than that previously used, to verify past data and to economically dewater mud which had been separated from the water. Because of a labor strike at the beginning of the processing season and rains which followed, the accomplishment of the first two objectives is in doubt. The quality of fruit was poor and caused the processor to alter his method of operation. Rather than operate independent systems, it was necessary for the processor to split the product into two flows, part of the tomatoes went through conventional processing and part went through the demonstration system.

The emphasis of this report will be in reporting on results obtained from dewatering mud by a horizontal vacuum belt. The 1976 test results did show that the cleaner was effective in cleaning tomatoes and that minimal water was required. Because of problems previously mentioned, data collected in 1976 can not be directly compared with that obtained the previous two years.

WATER RECYCLE

Figure 1 is a schematic drawing which illustrates the major components of the water recycle system and the method of processing the mud. As shown in figure 1, the key process elements are a solids trapping false bottom, an ejector for solids transport, a screen with a solid hopper, a soil solids separating swirl concentrator, a gravity clarifier - thickener and a tube flocculator. The soil solids passed through the false bottom and were transported by an ejector to the gravity screen. The screen removed gross solids such as vines, rocks and other debris. After screening the water flowed by gravity to the swirl concentrator. Grit, sand and heavy particles in the incoming water were separated and discharged as a fixed underflow from the swirl concentrator to a gravity thickener. Overflow from the thickener could be chemically treated in the tube flocculator and returned. The swirl concentrator returned approximately 80% of flow back to the dump tank. Overflow from the thickener tank could also be returned to the dump tank or be discharged to the sewer, the direction of flow was determined by a level control in the dump tank.

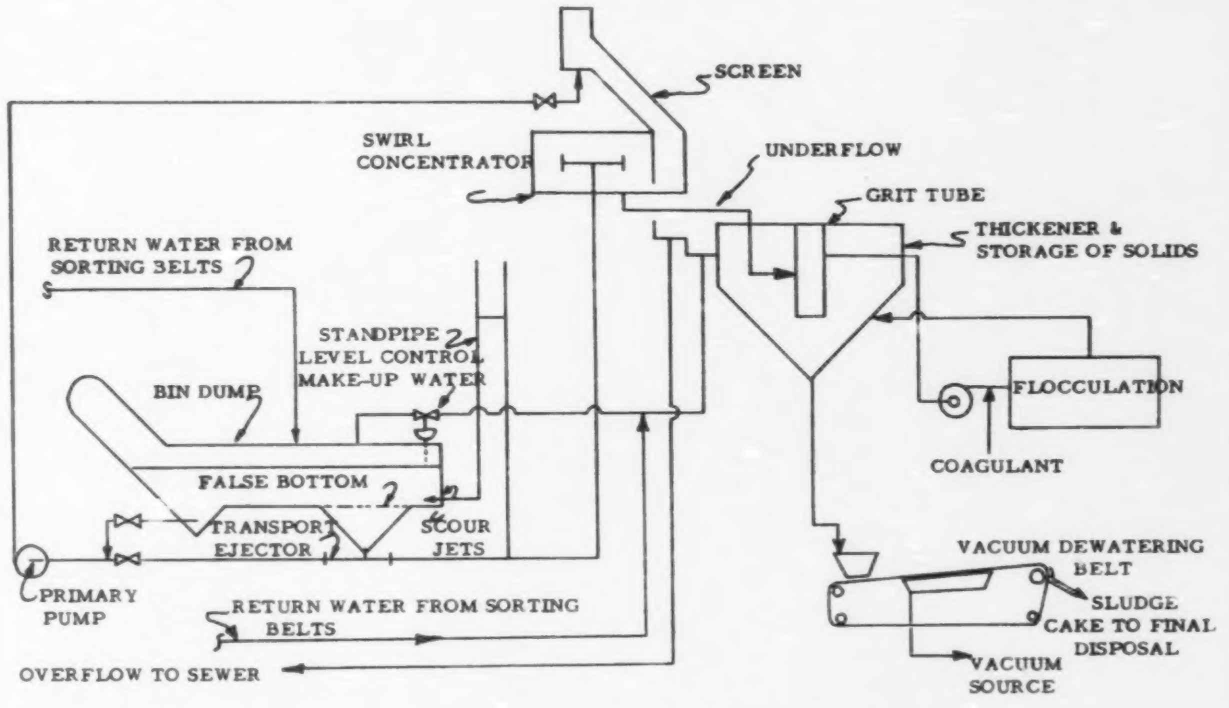
SCREEN
SWIRL CONCENTRATOR
UNDERFLOW
GRIT TUBE
THICKENER & STORAGE OF SOLIDS
RETURN WATER FROM SORTING BELTS
STANDPIPE
LEVEL CONTROL
MAKE-UP WATER
BIN DUMP
FLOCCULATION
FALSE BOTTOM
COAGULANT
TRANSPORT EJECTOR
SCOUR JETS
VACUUM DEWATERING BELT
PRIMARY PUMP
SLUDGE CAKE TO FINAL DISPOSAL
RETURN WATER FROM SORTING BELTS
OVERFLOW TO SEWER
VACUUM SOURCE

FIG. 1 FLOW DIAGRAM OF WATER RECYCLE SYSTEM.

VACUUM BELT DEWATERING UNIT

Prior to 1976, sludge from the thickener tank was periodically withdrawn for disposal onto agricultural land. Data indicated that the solids content of the sludge was generally 20 to 25% solids. Higher solids in the mud would decrease the disposal costs. A low cost, vacuum belt dewatering system was fabricated prior to the 1976 season and evaluated as a method of increasing the solids content of mud removed from the thickener tank.

Figure 2 is a schematic of the dewatering unit. The major components are as follows:

1. Sludge receiving hopper with level control.
2. Vacuum belt with variable speed chain drive.
3. Vacuum source and filtrate withdrawal pump.
4. Filter cake removal and belt cleaning.

Sludge from the thickener tank was delivered to the hopper by gravity. The feed to the hopper was controlled by a level switch inside the hopper. The level switch was connected to an air operated sludge level control valve, installed in a line between the thickener tank and the hopper.

Two types of belting material were used in the dewatering study. One belt was made of polypropylene monofilament, 6.4 ounces per square yard and with a porosity of 125 cfm of air at 20 inches of mercury. The second belt was made of nylon high twist, 8 ounces per square yard and with a porosity of 40 to 70 cfm at 20 inches of mercury.

A NASH water sealing vacuum pump, with a 2 hp motor turning at 1950 rpm, was used to maintain vacuum within the vacuum chamber. During a test, the pump operated at a vacuum of 36 inches of water and pulled approximately 10 cfm of air through the belt. Sludge was dewatered as it moved over the vacuum chamber. The filtrate from the sludge was continuously removed from the vacuum chamber by a diaphram pump.

The dewatered sludge cake was scraped off the belt after it passed over the pull drive mechanism. It was collected in a gondola and eventually transported to a landfill for disposal. The washing of the vacuum belt was by means of spray nozzles located immediately upstream of the sludge hopper. The belt was cleaned before receiving a new layer of sludge. Rinse water was collected and transported by a diaphram pump to the thickener tank.

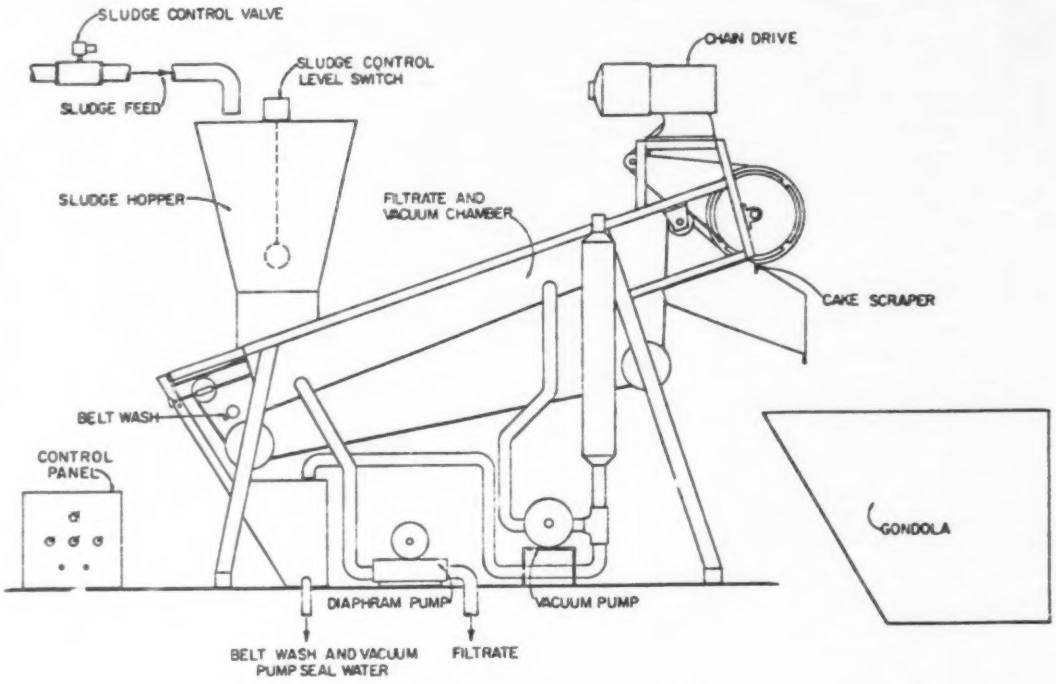
SLUDGE CONTROL VALVE
SLUDGE FEED
SLUDGE CONTROL LEVEL SWITCH
CHAIN DRIVE
SLUDGE HOPPER
FILTRATE AND VACUUM CHAMBER
CAKE SCRAPER
BELT WASH
CONTROL PANEL
GONDOLA
DIAPHRAM PUMP
VACUUM PUMP
BELT WASH AND VACUUM PUMP SEAL WATER
FILTRATE

FIG. 2 ASSEMBLY OF VACUUM BELT DEWATERING UNIT

The pertinent operational variable of the vacuum belt are as follows:

1. Sludge solids loading rate
2. Type of vacuum belt
3. Vacuum applied
4. Belt speed
5. Cake thickness
6. Type and concentration of chemical for sludge conditioning.

An intensive program evaluation of the sludge dewatering unit was conducted between September 9 and 23. During this time period, the mud removal and the sludge dewatering units were operated and monitored on a continuous, round the clock basis. The dewatering operation, except on September 15 and 22, 1976, was evaluated without chemical coagulation/ flocculation. On those two days various concentrations of a polymer (Calgon Cat-Floc) were added to the tube flocculator.

After several trial and error efforts, a schedule for the withdrawal of sludge from the thickener tank was established. Sludge was permitted to thicken in the tank for 4 to 5 hours prior to dewatering. It was found that the vacuum belt could operate for approximately 1 hour before the feed from the thickener tank became too dilute for further dewatering. When this occurred, the feed would be stopped and the mud permitted to accumulate in the thickener tank. After some 4 to 5 hours the dewatering system would be started up again and run until the feed became dilute.

DATA COLLECTION AND INTERPRETATION

Information and samples were collected which permitted an analysis of the performance of the vacuum dewatering system. Data was gathered for variation in belt speed, feed sludge and sludge cake on the belt, sludge cake and filtrate production rate, total solids of the feed sludge and effect of chemical coagulation. The results from this evaluation have been interpreted in terms of sludge solids loading rate, dewatering efficiency, drying factor, sludge volume reduction efficiency and solids recovery efficiency.

Data are presented in table 1 for the dewatering of mud without the use of chemical coagulants. During the test period the belt speed varied from 1.3 to 3.6 ft/min. The thickness of the sludge feed varied from 3/16 to 10/16 inches with an average of 7/16 inch; the sludge cake thickness

TABLE 1. RESULTS OF TOMATO MUD DEWATERING WITH VACUUM BELT UNIT (Without Chemical Coagulation)

Date	Time	Belt Speed (ft/min)	Mud Thickness (in)		Sludge Loading Rate (gph/ft²)	Cake Production Rate (gph/ft²)	Total Solids Conc. (%)			Filtrate Production Rate (gph/ft²)
			Feed	Cake			Feed	Cake	Filtrate	
9/9/76	4:20p	3.6	4/16	2/16	8.6	4.3	25.7	46.9	1.3	2.9
9/9/76	5:00p	2.2	3/16	2/16	3.9	2.6	29.5	42.5	1.1	4.8
9/9/76	6:30p	1.3	4/16	3/16	3.1	2.3	25.9	36.0	2.0	5.2
9/10/76	2:15p	3.6	4/16	2/16	8.6	4.3	32.8	45.7	1.3	2.0
9/10/76	5:10p	3.6	4/16	2/16	8.2	4.2	16.3	28.3	1.9	4.0
9/10/76	6:05p	3.6	9/16	6/16	18.9	12.6	14.5	25.8	1.6	4.2
9/10/76	10:00p	3.6	8/16	4/16	16.8	8.4	29.9	50.0	1.7	2.3
9/10/76	11:20p	3.6	5/16	3/16	10.7	6.4	16.1	26.0	1.8	3.8
9/11/76	4:30a	3.6	6/16	4/16	12.8	8.5	12.0	18.5	3.1	4.0
9/11/76	10:00a	3.6	7/16	4/16	14.9	8.5	20.5	38.0	1.2*	4.0
9/11/76	4:10p	3.6	10/16	8/16	21.3	17.0	30.1	38.6	1.4	3.8
9/11/76	5:05p	3.6	8/16	4/16	17.0	8.5	20.2	34.6	1.7	2.9
9/12/76	1:10a	3.6	9/16	6/16	19.2	12.8	20.4	32.0	3.9	4.6
9/13/76	12:30p	3.6	6/16	4/16	12.8	8.5	38.2	54.4	1.2*	4.6
9/13/76	4:10p	3.6	8/16	4/16	17.0	8.5	31.4	43.1	1.9	2.7
9/13/76	9:30p	3.6	8/16	6/16	17.1	12.8	24.9	33.9	1.6	2.9
9/14/76	1:00a	3.6	8/16	7/16	17.0	14.9	28.8	36.7	1.2	2.6
9/14/76	2:00a	3.6	6/16	4/16	12.8	8.5	27.2	37.2	1.2	3.5
9/14/76	10:00a	3.6	8/16	7/16	17.0	14.9	31.3	59.3	1.8	3.0
9/23/76	12:00a	1.3	8/16	6/16	6.1	4.6	45.9	55.6	8.0	2.5
9/23/76	5:10a	2.2	7/16	5/16	9.1	6.5	33.4	49.5	5.5	5.0
Average			7/16	4/16	13.0	8.6	26.4	39.7	2.2	3.6
Range		(1.3-3.6)	(3/16-10/16)	(2/16-8/16)	(3.1-21.3)	(2.3-17.0)	(12.0-38.2)	(18.5-59.3)	(1.1-8.0)	(2.0-5.2)

* Estimated value

ranged from 2/16 to 8/16 inches with an average thickness of 4/16 inch. The sludge loading rate varied between 3.1 and 21.3 gph/ft^2, with an average of 13 gph/ft^2. The total solids concentrations for the feed sludge, sludge cake and filtrate ranged from 12.0 to 38.2, 18.5 to 59.3 and 1.1 to 8.0 percent by weight respectively with an average of 26.4, 39.7 and 2.2 percent by weight.

The rates of sludge loading and sludge cake production were estimated from the measured feed sludge thickness and the belt speed. As an illustration, data was taken from September 9 at 4:20 P.M. and calculated as follows:

Feed sludge = 4/16 = 0.021 ft.
Belt speed = 3.6 ft/min
Belt width = 9 in - 0.75 ft
Effective belt surface area = 3 ft^2
Sludge surface loading area = 0.75 x 3.6 = 2.7 ft^2/min.

Therefore the sludge loading rate is:

$$= \frac{2.7 \text{ ft}^2/\text{min} \times 0.021 \text{ ft} \times 7.48 \text{ gal/ft}^3 \times 60 \text{ min/hr}}{3 \text{ ft}^2}$$

$$= 8.6 \text{ gph/ft}^2$$

Similarly, the sludge cake production was estimated to be 4.3 gph/ft^2 since the cake thickness for this particular run was 2/16 inch.

On September 15 and 22, the vacuum belt was used to dewater sludge which had resulted from the use of chemical flocculation of thickener overflow. Data for this time period is presented in table 2. In comparing the data with that in table 1, certain observations can be made:

1. A slight increase in the thickness of sludge feed and cake was noted during the time coagulation was used.

2. There was an increase in the sludge loading rate and in sludge production when chemicals were used.

3. There was a significant increase in the total solids concentration of the sludge feed and cake when chemicals were used.

TABLE 2. RESULTS OF TOMATO MUD DEWATERING WITH VACUUM BELT UNIT

(With Chemical Coagulation)

Date	Time	Belt Speed (ft/min)	Mud Thickness (in)		Sludge Loading Rate (gph/ft^2)	Cake Production Rate (gph/ft^2)	Total Solids Conc. (%)			Filtrate Production Rate (gph/ft^2)	Calcon Cat-Floc Concentration (mg/l)
			Feed	Cake			Feed	Cake	Filtrate		
9/15/76	1:40a	3.6	9/16	7/16	19.2	14.9	41.3	56.2	3.0	4.0	15
9/15/76	8:40a	3.6	7/16	5/16	16.9	12.1	35.8	55.7	1.5	3.0	15
9/15/76	4:00p	3.6	6/16	5/16	14.5	12.1	43.6	58.6	2.5	2.6	15
9/22/76	5:00p	3.6	9/16	5/16	21.8	12.1	38.2	58.2	2.8	3.5	20
9/22/76	6:15p	2.2	8/16	4/16	10.4	5.2	44.7	56.9	5.1	5.5	20
9/22/76	8:00p	1.3	8/16	6/16	6.1	4.6	39.6	57.6	4.5	2.5	20
Average			8/16	5/16	14.8	10.2	40.5	57.2	3.2	3.5	17.5
Range			(6/16- 9/16)	(4/16- 7/16)	(6.1- 21.8)	(4.6- 14.9)	(35.8- 44.7)	(55.7- 58.6)	(1.5- 5.1)	(2.5- 5.5)	(15- 70)

4. There was also a significant increase in the total solids concentration of the filtrate when adding chemicals and reasons for this increase are not known.

DISCUSSION OF RESULTS

The important parameters in evaluating a sludge dewatering unit includes: sludge solids loading rate, cake solids production rate, dewatering efficiency and solids recovery efficiency. The sludge solids loading rate was estimated to be the sum of rates of solids collected in the filtrate and solids in the cake. The former were estimated from the filtrate production rates and the solids concentrations of the filtrate. The rate of solids production in the cake was estimate from the sludge cake production and the solids concentration of the cake. The specific gravity of the cake was estimated to be 1.41.

The sludge dewatering efficiency looks at the efficiency of removing water from sludge and is defines as:

$$\text{D.E.} = \left[\frac{(\text{filtrate water out})}{\left(\begin{matrix}\text{filtrate} \\ \text{water out}\end{matrix} + \begin{matrix}\text{cake} \\ \text{water out}\end{matrix} \right)} \right] \times 100$$

The drying factor reflects on an increase of solids concentration of the cake that is produced as opposed to sludge prior to dewatering. This parameter is defined as the ratio of solids concentration of the cake to that of the sludge. The sludge volume reduction efficiency, representing the percent volume reduction in dewatered sludge is an important factor that considers the volume of cake being produced and disposed of. Efficiency is defined as:

$$\left(1 - \frac{\text{cake vol. prod. rate}}{\begin{matrix}\text{cake vol.} \\ \text{prod. rate}\end{matrix} + \begin{matrix}\text{filtrate prod.} \\ \text{rate}\end{matrix}} \right) \times 100$$

The final parameter that was evaluated was solids recovery efficiency and is defined as:

$$\left(\frac{\text{cake solids}}{\text{cake solids + filtrate solids}} \times 100 \right)$$

Table 3 presents data for dewatering with the vacuum belt during the time period when chemical coagulation was not used. Solids loading rates ranged from 9.8 to 117.3 lbs/hr - ft^2, with an average of 38.9 lbs/hr-ft^2. Cake production ranged from 8.9 to 116.8 lbs/hr -ft^2 with an average of 38.3 lbs/hr -ft^2. The dewatering efficiency was between 17 to 70 percent with an average of 37 percent. The drying factor ranged between 1.21 and 1.89 with an average of 1.53. The sludge volume reduction efficiencies ranged from 17 to 49 percent with an average of 30 percent. The solids recovery efficiencies ranged from 91 to 99 percent with an average of 97 percent.

The effect of chemical treatment of thickener overflow on sludge dewatering was investigated for six runs that took place on 9/15 and 9/22. The chemical used was a cationic polymer (Calgon Cat-Floc). The chemical dosage for the three runs made on 9/15 was 15 mg/l; and for 9/22 it was 20 mg/l. Results for these conditions and the ranges are given in table 4.

In comparing the performance of the vacuum belt as shown in table 3 and 4, it was noted that a significantly higher sludge solids loading rate and cake solids production rate were obtained with chemical coagulation than without. The average solids loading rate with chemical usage was 76.2 lbs/hr-ft^2 as opposed to 38.9 lbs/hr-ft^2 without chemical use. Similarly, the average solids production rate with chemical addition was 75.2 lb/hr-ft^2, in contrast to 38.3 lb/hr-ft^2 without chemical.

It has been estimated that the unit cost for the vacuum belt dewatering unit is $2 per ton of dry solids. This is in contrast to the $12 to $29/ton of dry solids for the dewatering of sewage sludge by conventional rotary drum vacuum filters, filter presses or centrifuges. The unit cost of $2/ton is estimated on the following assumptions:

1. Tomato production rate - 120 tons/hr.
2. Solids production rate - 15 lbs soil/ton tomatoes.
3. Period of operation - 60 days.
4. Initial capital cost - $5,000 with a 5 year life and straight line depreciation.
5. Manpower - 2 man hours/day at $10/hr.
6. Total power - 3 HP.

TABLE 3. PERFORMANCE EVALUATION OF TOMATO MUD DEWATERING WITH VACUUM BELT UNIT
(Without Chemical Coagulation)

Date	Time	Sludge Solids Loading Rate (lb/hr/ft^2)	Cake Solids Production Rate (lb/hr/ft^2)	Dewatering Efficiency (%)	Drying Factor	Sludge Volume Reduction (%)	Solids Recovery (%)
9/9/76	4:20p	24.0	23.7	47	1.82	40	79
9/9/76	5:00p	12.9	12.5	70	1.44	35	97
9/9/76	6:30p	9.8	8.9	70	1.39	31	91
9/10/76	2:15p	23.1	22.9	38	1.39	32	99
9/10/76	5:10p	12.6	12.0	52	1.74	49	95
9/10/76	6:05p	32.9	32.3	27	1.78	25	98
9/10/76	10:00p	51.2	50.9	27	1.67	21	99
9/10/76	11:20p	17.2	16.6	40	1.61	37	97
9/11/76	4:30a	15.8	14.8	33	1.54	32	93
9/11/76	10:00a	35.7	35.3	36	1.85	32	99
9/11/76	4:10p	72.4	72.0	20	1.28	18	99
9/11/76	5:05p	31.7	31.3	29	1.71	25	99
9/12/76	1:10a	44.2	42.7	29	1.57	26	97
9/13/76	12:30p	58.8	58.3	44	1.42	35	99
9/13/76	4:10p	42.0	41.6	29	1.37	26	99
9/13/76	9:30p	46.3	45.9	27	1.36	18	99
9/14/76	1:00a	59.4	59.1	17	1.27	15	99
9/14/76	2:00a	34.7	34.3	36	1.37	29	99
9/14/76	10:00a	117.3	116.8	17	1.89	17	99
9/23/76	12:00p	34.3	32.6	44	1.21	35	95
9/23/76	5:10a	44.1	38.8	50	1.48	43	94
Average		38.9	38.3	37	1.53	30	97
Range		(9.8-117.3)	(89-116.8)	(17-70)	(1.21-1.89)	(17 49)	(91-99)

TABLE 4. PERFORMANCE EVALUATION OF TOMATO MUD DEWATERING WITH VACUUM BELT UNIT
(With Chemical Coagulation)

Date	Time	Sludge Solids Loading Rate (lb/hr/ft^2)	Cake Solids Production Rate (lb/hr/ft^2)	Dewatering Efficiency (%)	Drying Factor	Sludge Volume Reduction (%)	Solids Recovery (%)
9/15/76	1:40a	108.4	107.4	28	1.36	21	99
9/15/76	8:40a	86.5	86.1	26	1.56	20	99
9/15/76	4:00p	93.6	93.1	25	1.34	18	99
9/22/76	5:00p	92.9	92.1	31	1.52	22	99
9/22/76	6:15p	40.5	38.2	62	1.27	51	94
9/22/76	8:00p	35.4	34.5	44	1.45	35	97
Average		76.2	75.2	36	1.42	28	98
Range		(35.4-108.4)	(34.5-107.4)	(26-62)	(1.27-1.56)	(18-51)	(94-99)

During the course of this project the newly developed vacuum belt dewatering unit has only been evaluated on the dewatering of sludge from tomato dump tank water. Its performance on sewage sludge is unknown and makes a comparison with other existing sludge dewatering devices rather difficult. What has been evaluated appears to be an efficient and cost effective device for dewatering mud.

REFERENCES

1. Rose, W. W., Katsuyama, A. M., and Wilson, G. E. Tomato cleaning and water recycle. Proceedings of the Sixth National Symposium on Food Processing Wastes EPA 600/2-76-224 (1975)

2. Wilson, G. E., Rose, W. W., and Huang, J. Y. C. Tomato flume water recycle with off-line mud removal. Proceedings of the Seventh National Symposium on Food Processing Wastes EPA 600/2-76-304 (1976)

3. Krochta, J. M., Graham, R. P., and Rose, W. W. Cleaning of tomatoes using rotating rubber discs. Food Technology 28(12):26 (1974)

4. Carroad, P. A., Krochta, J. M., and Rose, W. W. Water/energy trade-off in cleaning tomatoes. Food Technology 30(3):24 (1976)

5. Carroad, P. A., and Rose, W. W. Water recycle improves disc cleaning of tomatoes. Food Technology 31(3):92 (1977)

REMOVAL OF SUSPENDED SOLIDS AND ALGAE FROM AEROBIC LAGOON EFFLUENT TO MEET PROPOSED 1983 DISCHARGE STANDARDS TO STREAMS

by

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ABSTRACT

A new technology has been applied to the removal of algae from aerobic lagoons. This involves a two-step process which employs electrocoagulation together with a specially designed dissolved air flotation basin. The performance of this system is very effective in removal of algae from aerobic lagoon effluent.

INTRODUCTION

A Swift Hog Packinghouse Plant located in Moultrie, Georgia processes approximately 2,000 hogs per day. These are dressed and cut in a one-shift operation. Water used to carry out this operation is approximately 650,000 gallons per day. Following good in-plant waste control practices plus extensive mechanical pretreatment, this plant employs an anaerobic lagoon with an area of approximately 1-1/2 acres and a depth of 14 feet. The anaerobic lagoon effluent is directed to a 19-acre aerobic lagoon. Details on construction and design factors of both the anaerobic and aerobic lagoon have been described in the literature (1).

In spite of the anaerobic and aerobic lagoons, the plant determined it would not be able to meet either 1977 nor 1983 effluent limitations with the original treatment system. Effluent from the aerobic lagoon is discharged to Okapilco Creek.

A fundamental problem with the lagoon system at Moultrie, as in other systems of its type, is the growth of algae in the aerobic lagoon.

The problem of algae in aerobic lagoons has been studied elsewhere and is discussed in (2) (4). Basically, algae can be described as hydrophilic biocolloids with apparent negative surface charges. Oftentimes, algae are

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particulates 3 to 15 microns in size and their specific gravity is approximately that of the water. Destabilization of algae suspensions has been accomplished with lime, alum, magnesium ions, ferric sulfate, and many synthetic polyelectrolytes (3) (5). pH is an important factor with regard to any chemical treatment for removal of algae from water.

ALTERNATE SOLUTIONS TO MEET EFFLUENT LIMITATIONS

The solution to the problem was approached from many directions. These included the following: (a) modified in-plant operations and improved pretreatment to diminish the problem, (b) consider the possibility of working with the municipal plant for treatment of all Swift wastewater, (c) use of aerobic lagoon effluent as an irrigation source, (d) employ algae destruct chambers of the Chem Pure Inc. type, (e) use of dissolved air flotation as described in the literature, (f) consider algae-eating fish in the aerobic lagoon, (g) use of extended aeration and sand filter tertiary treatment, (h) use services of algae harvesting facilities as described by the WRAP System, (i) physical-chemical treatment using LectroClear process, (j) Sweco concentrato, and (k) Biological Water Purification reed sand filter system.

Of the above alternate approaches to the wastewater treatment problem at Moultrie, our Engineering Department settled on the following three combined with improved pretreatment as being the more efficient and reliable, when considering the strict standards of the 1983 Effluent Limitations: (a) extended aeration and sand filter tertiary treatment, (b) water reclamation by algae harvesting [WRAP System], (c) physical-chemical treatment with LectroClear.

COST EVALUATION OF TREATMENT ALTERNATIVES

The three selected alternatives mentioned above were then fully evaluated in terms of Capital Equipment and Cost and Operating and Maintenance Cost. A cash flow of the three processes indicated the physical-chemical treatment, using the LectroClear principle, was the most economical. At the completion of this cost analysis study, plans were then laid for the design and installation of a LectroClear System capable of meeting proposed 1983 effluent limitations. These limitations, together with the limitations for 1977, are given in Tables 1 and 2.

TABLE 1. MOULTRIE - EFFLUENT LIMITATIONS
(WATER QUALITY LIMITED STREAM)
JULY 1, 1977 - JUNE 30, 1979

Effluent	Kg/Day (Lbs./Day)		Basis 0.65 Mgd		Other Units
	Daily Avg.	Daily Max.	Daily Avg.	Daily Max.	
BOD_5 *	25 (54)	50 (108)	10	20 ppm	
TSS **	74 (163)	148 (326)	30	60 ppm	
Oil & Grease ***	24 (52)	48 (104)	10	20 ppm	
Fecal Coliform					Max. 400 org./ 100 ml.
Ammonia (Nitrogen)****	10 (22)	20 (44)	4	8 ppm	
pH					6.0 - 9.0
Settleable Solids					Not to exceed 0.1 ml/1

* Based on stream water quality model.
** Based on 1977 Meat Packing Guidelines - max. Lwk 654 M#Lwk x .25#/M#Lwk.
*** Based on 1977 Meat Packing Guidelines - max. Lwk 654 M#Lwk x .08#/M#Lwk.
****Based on 1983 Meat Packing Guidelines - (4 ppm) (8.345) (.650 Mgd.)

TABLE 2. MOULTRIE - PROPOSED EFFLUENT LIMITATIONS
(WATER QUALITY LIMITED STREAM)
JULY 1, 1983

Effluent	Kg/Day (Lbs./Day)		Basis 0.65 Mgd		Other Units
	Daily Avg.	Daily Max.	Daily Avg.	Daily Max.	
BOD_5	26	52	5	10 ppm	
TSS	46	92	9	18 ppm	
Oil & Grease			10 mg/1		
Ammonia (Nitrogen)	22	44	4	8 ppm	
Fecal Coliform					Max. 400 Org/ 100ml
pH					6.0 - 9.0
Settleable Solids					Not to exceed 0.1 ml/1
Dissolved Oxygen					6 ppm.

DECISION TO GO TO ELECTROCOAGULATION-DISSOLVED AIR FLOTATION

The plant was especially interested in selecting a low Capital Equipment figure together with a low Operating Cost figure. Stipulations put forth by the plant and included in this design were the following: (a) system should have the capability of the aerobic lagoon effluent in a single-shift (8 hours) five day operation. This stipulation automatically increased the capacity of the unit by threefold, (b) space was not a premium item under the condition of this project, (c) labor allotted to the wastewater treatment system would be held to a minimum.

Annual Operating and Maintenance Cost of the LectroClear installation based on a design of 1,500 gallons per minute is an estimated maximum $75,000 per year. Annual Fixed Cost and Depreciation Cost are an estimated $25,000 per year based on a straight line 15 year depreciation. Total Annual Operating Costs and Fixed and Depreciation Costs are an estimated maximum $100,000 per year for the specific plant at Moultrie, Georgia.

DESIGN FACTORS

The design of the LectroClear unit installed in Moultrie, Georgia was based on the following parameters: (a) a single design would be made which would meet both 1977 and 1983 Effluent Limitations. The primary difference in the quality of the treated wastewater would be the amount of metal coagulant employed [alum].

Beaker Scale tests on the removal of algae from Moultrie wastewater showed the following: (a) optimum reults were achieved when the combination of electrocoagulation and dissolved air flotation were employed, (b) energy input in the electrocoagulation cell would require not more than 2 ampere-minutes per gallon of wastewater treated, (c) 50% dissolved air recirculation using pressures between 50 to 75 psig would be adequate, (d) to meet the 1977 Standards, approximately 80 -150 ppm of alum would be required, while to meet the proposed 1983 Limitations approximately 150-250 ppm of alum would be used, (e) size of the basin would be 64- feet long, 15-feet wide, and 5-feet deep, (f) dwell time in the electrocoagulation cell would be 2-1/2 minutes when operated at 1,500 gpm. Details on mechanisms and design of electrocoagulation cells have been reported elsewhere (6) (7) (8) (9) (10). Photographs of the electrocoagulation cell are shown in Figures 1 and 2. Photographs of the overall installation, showing both flotation basin and electrocoagulation cell, are shown in Figures 3 and 4.

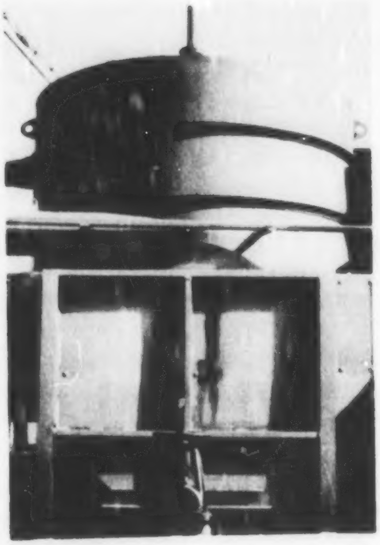

Fig. 1 Electrocoagulation Cell. Bottom section contains electrodes.

Fig. 2 Inside view of bottom of Electrocoagulation Cell. Note close spacing between electrodes.

Rectifier, powering the electrocoagulation cell, is capable of 24 Volts DC and 3,000 Amperes. Pump employed for the 50% dissolved air recycle employs 50 Hp.

RESULTS

Installation of all basic hardware was completed in January 1976. Several one-week trial runs were carried out to evaluate capabilities of the installation and also to debug the operation.

Performance of the LectroClear installation during various runs is shown in Table 3.

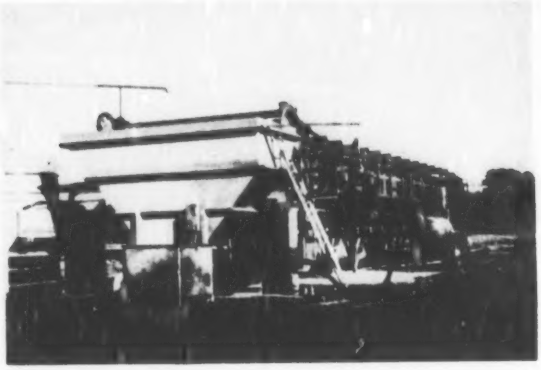

Fig. 3. Flotation Basin. Electrocoagulation Cell is at the left. Note skimming storage in front of basin.

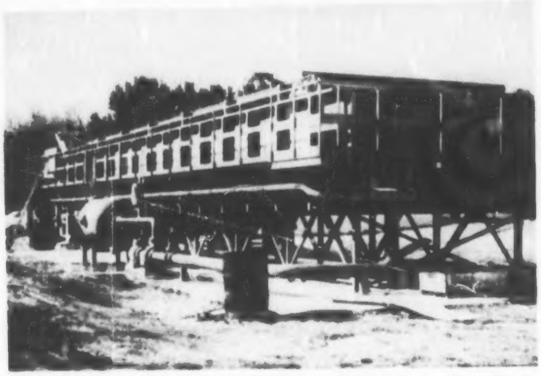

Fig. 4. Rear View of Flotation Basin. Tank is pressure chamber for DAF.

TABLE 3. WATER ANALYSES OF MOULTRIE-LECTROCLEAR TESTS

Sample	Date**	BOD (mg/l)	TSS (mg/l)	TKN (mg/l)	pH	FOG (mg/l)	Fecal Coliform (mg/l)
Lagoon	9/20/76	8	53	33.0	7.7	---	---
LC Effluent*	9/20/76	5	5.5	26.5	6.4	---	---
Lagoon	9/21/76	21.6	64	47.9	---	5.1	---
LC Effluent*	9/21/76	3.5	4.5	12.3	---	5.1	---
Lagoon	9/22/76	17.3	55	24.6	---	4.0	---
LC Effluent*	9/22/76	2.7	2.0	9.7	---	2.8	---
Lagoon	9/23/76	20	44	23.0	7.6	---	---
LC Effluent*	9/23/76	5	5	13.0	6.9	---	---
Lagoon	9/24/76	14	47	24.0	7.5	---	---
LC Effluent*	9/24/76	5	7	14.0	7.0	---	---
Lagoon	1/4/77	41	56	20.0	9.2	---	---
LC Effluent*	1/4/77	5	9	13.0	7.2	---	0

* LectroClear Effluent - Treatment is 150 ppm Alum, 2 ppm Anionic Polymer 1.2 Ampere-minutes in Electrocoagulation Cell, 50% recycled DAF, all samples are daily composite tests.

Solids content of the skimmings are given in Table 4.

TABLE 4. MOULTRIE - ALGAE SLUDGE ANALYSES LECTROCLEAR BASIN (WET BASIS)

Date	Total Solids, %	TKN, %	Equiv. Protein, %	Aluminum, %
3/31/76	3.9	---	---	---
3/31/76	4.0	---	---	---
3/31/76	4.2	---	---	---
3/31/76	3.6	---	---	---
3/31/76	3.9	0.245	1.56	---
4/1/76	4.9	0.25	1.56	0.44
4/2/76	7.8	0.27	1.69	---
8/21/76	5.4	0.28	---	---
9/21/76	7.0	0.28	---	---

The analyses of both as generated skimmings and skimmings on a dry basis are given in Table 5.

TABLE 5. MOULTRIE SKIMMINGS ANALYSIS (DRY BASIS)

Sample	Date	Phosphorus, %	TKN, %	Equiv. Protein, %	K_2O
Comp. 1-5	3/31/76	1.71	7.88	49.4	0.70

It is anticipated that approximately 3,000 gallons per day of algae skimmings will be generated and removed from the LectroClear basin.

Due to the fertilizer value of the skimmings, the local farmers were interested in obtaining possession of the skimmings. In the final analyses, a contract will be made with a local farmer whereby he would guarantee the removal of skimmings on a daily basis. Figure 5 shows farmer removing the first few runs of skimmings at the LectroClear wastewater treatment facility.

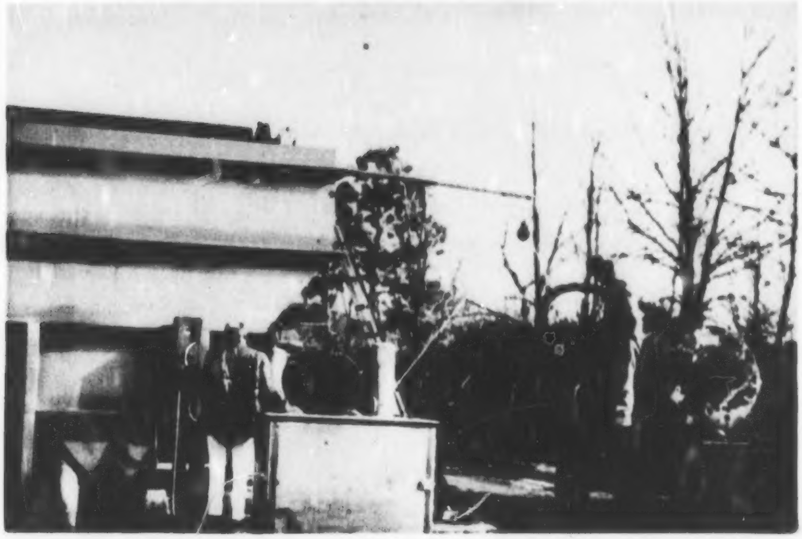

Fig. 5. Farmer removes skimmings from skimmings holding tank.

DISCUSSION

The results show that removal of algae at the Moultrie plant is a proportional function of alum dosage used. To meet proposed 1983 discharge limitations to the stream, alum addition of about 150-250 ppm will be required. The 1977 discharge limitations can be met with approximately 80-150 ppm of alum addition.

The data clearly demonstrate that the combination of electrocoagulation and recycle dissolved air flotation technologies can be effectively used to remove suspended solids from wastewaters. The unique sequential two-step operation employing electrocoagulation first, provides an ideal approach to destabilizing the hydrophilic biocolloid in the first-step, while recycle dissolved air flotation is used to remove the last traces of suspended material from the wastewater.

This particular installation was used to separate algae from wastewater. The concept, however, can be effectively used for handling any type of wastewater where suspended material, coagulated material (blood or albumen), or precipitated material (heavy metals) are present. It follows that this technology can be applied to all wastewaters where suspended, dispersed or emulsified foreign pollutants are present.

In summary, a new concept has been established for utilizing electrocoagulation and dissolved air flotation in a sequential two-step operation. The effectiveness of this technology surpasses the performance of processes heretofore industrially employed.

REFERENCES

1. Sollo, F. W. 15th Industrial Waste Conference, Purdue University, Lafayette, Ind. (1960).

2. Friedman, A. A., Peaks, D. A., and Nichols, R. L. Algae separation from oxidation pond effluents. Journal Water Poll. Control Fed., Pg. 111 (1977).

3. Caldwell, D. H., et al. Upgrading lagoons. Transfer Seminar Program, USEPA, Washington, D. C. (August 1973).

4. Bare, W. F. Rance, et al. Algae removal rising dissolved air flotation. Journal Water Pollution Control Fed., 47, 153 (1975).

5. Folkman, Yais and Wachs, Alberta M. Removal of algae from stabilization pond effluents by lime treatment.

6. Ramirez, E. R. Electrocoagulation of meat processing wastewater. WWEMA Industrial Conference (April 3, 1974).

7. Beck, E. C., Giannini, A. P., and Ramirez, E. R. Electrocoagulation clarifies food wastewater. Food Technology, Vol. 28, No. 2, Pg. 18, (1974).

8. Ramirez, Ernest R. Electrocoagulation clarifies food wastewater. Deeds & Data, WPCF (April 1975).

9. Ramirez, E. R., Johnson, D. L. and Clemens, O. A. Direct Comparison in physiochemical treatment of packinghouse wastewater between dissolved air and electroflotation. 31st Annual Purdue Industrial Waste Conference, West Lafayette, Ind. (May 1976).

10. Ramirez, E. R. and Clemens, O. A. Electrocoagulation techniques for primary treatment of several different types of wastewater. 49th Annual Conference, W.P.C.F., Minneapolis, Minn. (October 4, 1976).

EFFLUENT GENERATION, ENERGY USE AND COST OF BLANCHING

by

John L. Bomben*

INTRODUCTION

The wastewater produced by the blanching of vegetables for freezing or canning is a significant fraction of the total wasteload of the vegetable processing industry(1). Since the beginning of this industry, the basic design of blanchers has received little attention, but because of national concerns about wastewater and energy, changes in the design of conventional blanching systems are now being tested and evaluated.

This paper describes the characteristics of conventional blanchers and new blancher designs, the effluent generation and energy use of blanchers, and the cost of blanching with four different blanchers [water, steam (hydrostatic and vibratory spiral), and hot gas].

Material and Heat Balances

Figure 1 shows a material balance for blanching and cooling vegetables. (Table 1 lists the definitions of the symbols used in this paper). Total Solids of the vegetables is used as the unit for the material balance. In the effluent, Total Solids can be expressed as the equivalent Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC) and Suspended Solids (SS), which are all common units for measuring the organic load of an effluent. The initial weight of raw vegetables changes as the vegetables are blanched and cooled because of changes in water and solids content; the yields (Y_B and Y_C) represent these changes. Reducing the wasteload of blanching and cooling translates into reducing the hydraulic load (E_B and E_C) and the organic load (TS_{EB} and TS_{EC}) of the effluents. If air is used to cool the vegetables, then $E_C = 0$, and the cooling effluent is eliminated, but since much of the cooling is provided by evaporation of water, the yield after air cooling will be less than that after water cooling. Frozen vegetables are sold by weight, and thus the reduction in yield is a product loss. Bomben et al., (5) have reported on material balances measured with seven different vegetables using either air or water cooling.

Figure 2 shows a heat balance for blanching and cooling. Using C = 1 kcal/kg°C (1 BTU/lb°F) ΔH = 539 kcal/kg (970 BTU/lb) and $Q_L = 0$, the theoretical steam required to heat the vegetables to an enzyme inactivation temperature can be calculated to be 134 kg of steam/kkg of raw vegetables (268 lb steam/ton raw vegetables). The magnitude of Q_L determines the efficiency of an actual blancher; the smaller it is, the higher the efficiency.

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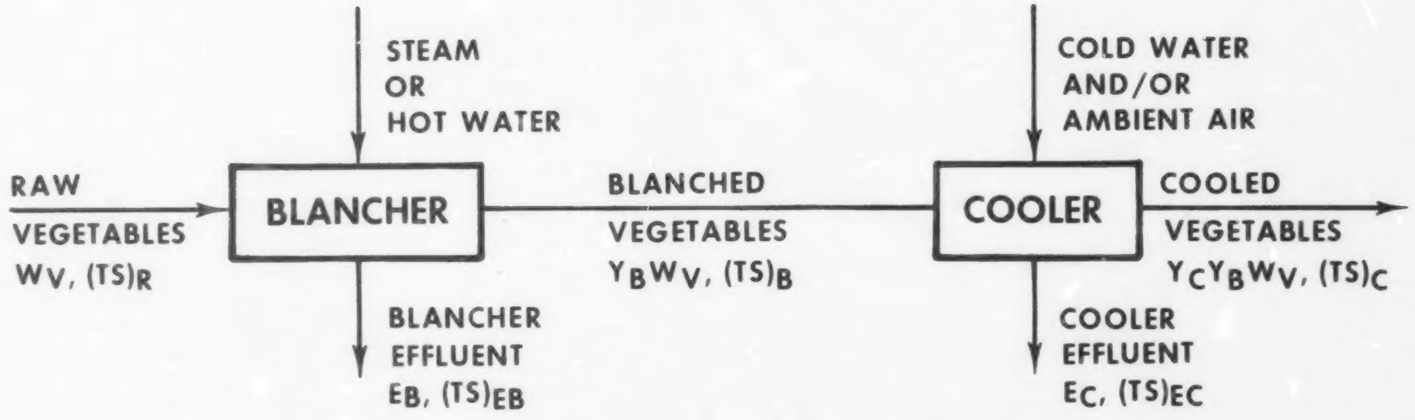
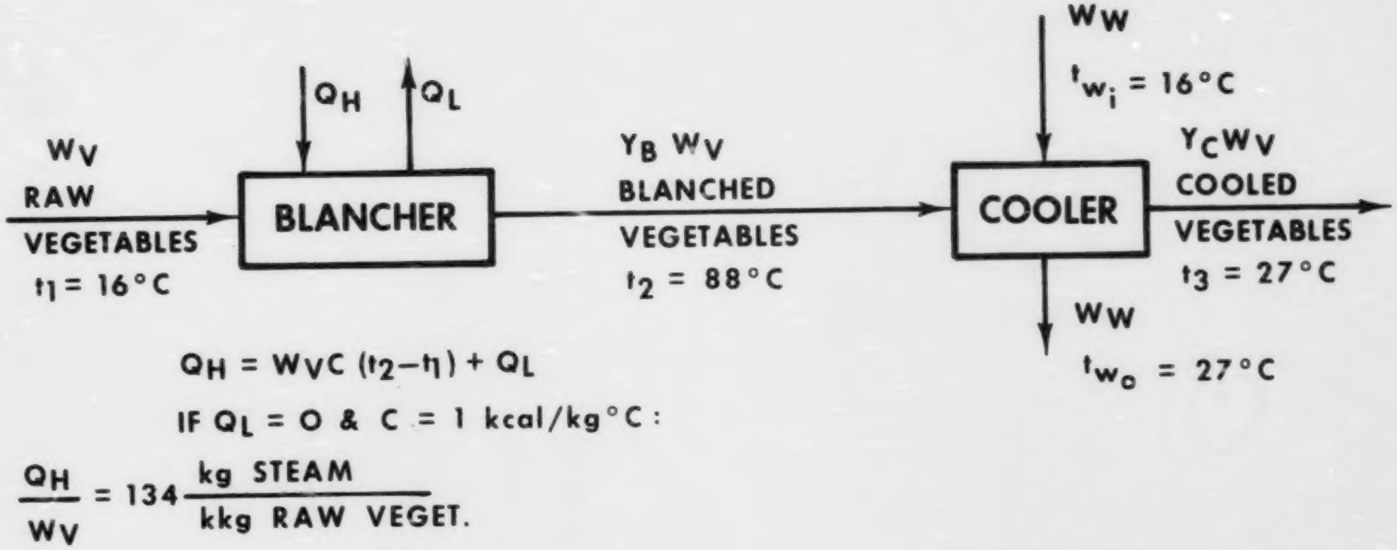

STEAM
OR
HOT WATER
RAW
VEGETABLES
WV, (TS)R
BLANCHER
BLANCHER
EFFLUENT
EB, (TS)EB
BLANCHED
VEGETABLES
YBWV, (TS)B
COLD WATER
AND/OR
AMBIENT AIR
COOLER
COOLED
VEGETABLES
YCYBWV, (TS)C
COOLER
EFFLUENT
EC, (TS)EC

$$W_V\,(TS)_R = Y_C Y_B W_V (TS)_C + \underbrace{E_B (TS)_{EB}}_{\substack{\text{BLANCHER}\\ \text{BOD}\\ \&\\ \text{SS}}} + \underbrace{E_C (TS)_{EC}}_{\substack{\text{COOLER}\\ \text{BOD}\\ \&\\ \text{SS}}}$$

Figure 1. Material balance for blanching and cooling.


W_V
RAW
VEGETABLES
$t_1 = 16°C$
BLANCHER
Q_H
Q_L
$Y_B W_V$
BLANCHED
VEGETABLES
$t_2 = 88°C$
COOLER
W_W
$t_{w_i} = 16°C$
W_W
$t_{w_o} = 27°C$
$Y_C W_V$
COOLED
VEGETABLES
$t_3 = 27°C$

$$Q_H = W_V C\,(t_2 - t_1) + Q_L$$

IF $Q_L = 0$ & $C = 1$ kcal/kg°C :

$$\frac{Q_H}{W_V} = 134\,\frac{\text{kg STEAM}}{\text{kkg RAW VEGET.}}$$

Figure 2. Heat balance for blanching and cooling.

TABLE 1. NOMENCLATURE

BOD = Biological Oxygen Demand, kg/kkg
C = heat capacity of vegetables or water, kcal/kg°C
E_B = hydraulic wasteload of blancher, l/kkg of raw vegetables
E_C = hydraulic wasteload of cooler, l/kkg of raw vegetables
ΔH = heat of vaporization for water, kcal/kg
Q_H = heat added to blancher, kcal/kg of raw vegetable
Q_L = heat lost from blancher, kcal/kg of raw vegetable
SS = Suspended Solids, kg/kkg
$(TS)_B$ = Total Solids in blanched vegetables, %
$(TS)_C$ = Total Solids in cooled vegetable, %
$(TS)_{EB}$ = Total Solids in blancher effluent, %
$(TS)_{EC}$ = Total Solids in cooler effluent, %
$(TS)_R$ = Total Solids in raw vegetable, %
t_1 = temperature of raw vegetables, °C
t_2 = temperature of blanched vegetables, °C
t_3 = temperature of cooled vegetables, °C
tw_i = temperature of inlet cooling water
tw_o = temperature of outlet cooling water
W_v = feed rate of raw vegetables, kkg/hr
W_{evap} = water evaporated from vegetable, kkg/hr
Y_B = yield of blanched vegetables, %
Y_C = yield of cooled vegetables, %

On the basis of a heat balance using the temperatures shown in Figure 2, 5500 l of water/ kkg of raw vegetables (1320 gal/ton) are required for cooling vegetables after blanching. For air cooling the heat balance is more complicated because both heat of evaporation and sensible heat are transferred. If heat were transferred solely by evaporation, then for the temperatures in Figure 2, C = 1 kcal/kg and ΔH = 556 kcal/kg(1000 BTU/lb):

$$\frac{Wevap}{W_v} = \frac{Y_B C\ (t_2 - t_3)}{\Delta H + C\ (t_2 - t_3)} = 0.099 Y_B$$

Since Y_B usually equals approximately 95% (5), air cooling gives approximately a 10% reduction in the yield of vegetables. This loss can be counteracted by spraying the vegetables with water or blancher condensate, but in practice the weight loss and water addition do not balance, and there is a reduction of yield and some production of effluent(5).

Conventional Water and Steam Blanchers

Although conventional blanchers can be found in many forms, they can be put into two basic categories---water and steam blanchers. Table 2 shows the characteristics of wastewater from conventional steam and water blanchers. Blanchers are operated at varying conditions, and as a result, the characteristics of the wastewater can be quite different at different times in the

TABLE 2. WASTELOAD AND ENERGY USE IN CONVENTIONAL BLANCHING(1)

	Hydraulic Load (l/kkg)	BOD (kg/kkg)	SS (kg/kkg)	Steam Efficiency (%)
Hot Water				60
Snap Beans	124	0.69	0.13	
Lima Beans	821	0.65	--	
Peas	384	3.0	--	
Steam				5
Snap Beans	125	0.55	0.02	
Lima Beans	238	3.5	--	
Peas	313	4.3	--	

---

(1) Data taken from Ralls & Mercer(4), Lund(5), Lazar & Rasmussen(6), and Bomben(7).

same plant and from plant to plant. Generally, water blanchers produce a higher hydraulic load, but their organic load can be larger or smaller than that of steam blanchers. The amount of make-up water added to a water blancher is not a well-controlled variable and is probably the cause of the large difference in wasteloads reported in the literature. One plant operates a water blancher with no overflow(8), but since in that particular case (artichokes) citric acid is added to the blancher water, this has to be considered a special case, whose applicability to other blanched vegetables has not been investigated.

Data on the steam consumed by conventional blanchers are very limited, and typical values are shown in Table 2, where efficiencies are based on the theoretical steam consumption of 134 kg of steam/kkg of raw vegetables. Whereas the steam efficiency for the steam blancher was a measured value(7), the one for the water blancher was estimated(6). Generally, it appears reasonable to assume that water blanchers consume less steam than steam blanchers, but measurements of the actual efficiency of a water blancher are not available, or at least not well-known. The low efficiency of a steam blancher is attributable to the large losses of steam at the feed and discharge ends and the large uninsulated surface area.

New Blancher Designs

The Vibratory Spiral Blancher-Cooler is a design which departs markedly from that of conventional steam blanchers(9). Vibratory spiral conveyors are used to reduce the size of the steam blancher as compared to a water blancher, thereby reducing floor space and reducing surface area for heat loss. In addition, the spiral conveyor gives a simple means of sealing the feed and discharge of the blancher with vegetables thereby reducing this large heat loss associated with steam blanching. In addition to the blancher, this design also uses a vibratory spiral conveyor as an air cooler, where condensate from the blancher is sprayed on the vegetables as they are cooled. Thus, the only effluent for both blanching and cooling is the unevaporated, unabsorbed liquid leaving the cooler. This design has been tested in a large-scale pilot plant(7 and 9), and Table 3 shows the waste load and the steam efficiency obtained with that unit.

TABLE 3. WASTELOAD AND STEAM EFFICIENCY OF VIBRATORY BLANCHER-COOLER

	Hydraulic Load (l/kkg)	BOD (kg/kkg)	SS (kg/kkg)
Snap Beans	27.0	0.53	0.084
Lima Beans	27.9	0.90	0.54
Brussels Sprouts	15	0.43	0.073
Cauliflower	<3		
Broccoli	11	0.25	0.091

Steam Efficiency = 85% (Theoretical steam requirement = 134 kg/kkg of vegetables)

Hot-Gas Blanching uses the products of combustion along with steam as a heat transfer medium(4). A belt conveyor moves the vegetable through the hot gases and steam. This concept has been tested to the pilot plant stage, and Table 4 shows the waste load and energy requirements obtained with the pilot plant.

The Hydrostatic Steam Blancher uses water to seal the feed and discharge of a conventional steam blancher, thereby reducing the escape of steam from the blancher(10). Some of these blanchers are operating in freezing plants in California, and are reported to use 0.5 lb of steam per lb of vegetable(11). No data are available on the wasteload produced by this system, but it probably is approximately the same as that of a conventional steam blancher and flume as reported by Bomben et al.(5) and listed in Table 5.

TABLE 4. WASTELOAD AND STEAM EFFICIENCY OF HOT-GAS BLANCHING

	Hydraulic Load (1/kkg)	BOD (kg/kkg)
Snap Beans	0.06	<0.01
Corn-on-cob	58	0.86
Beets	93	0.63
Spinach	0.66	0.01
Peas	14	0.12

Steam efficiency = 56% (includes natural gas and electrical power for blower and is based on a theoretical steam consumption = 134 kg/kkg).

TABLE 5. WASTELOAD OF STEAM BLANCHING INCLUDING WATER COOLING(1)

	Steam Blanching Effluent		Water Cooling Effluent	
	Hydraulic Load (1/kkg)	BOD(2) (kg/kkg)	Hydraulic Load (1/kkg)	BOD(2) (kg/kkg)
Snap Beans	150	0.92	4930	1.6
Lima Beans	113	1.1	4960	3.4
Peas	191	2.7	4960	2.9

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(1) Data taken from Bomben, et. al.(5)
(2) Chemical Oxygen Demand was multiplied by 0.6 to get BOD(7)

Comparison of Waste Water and Energy Use

Table 6 compares the wastewater produced and the energy used for the blanching of snap beans by different methods. Wastewater characteristics are reported as hydraulic wasteload and organic wasteload (BOD & SS) and steam consumptions are reported as efficiency with respect to the theoretical value of 134 kg/kkg. In the case of Hot-Gas Blanching, the energy of the natural gas and the circulating blower are included in the calculation of the efficiency.

Hot-Gas Blanching produces the lowest wasteload. Its energy efficiency is an improvement over steam blanching, and it approaches that of water blanching. Despite its low wasteload, Hot-Gas Blanching is at a disadvantage

TABLE 6. WASTELOAD AND STEAM EFFICIENCY OF DIFFERENT METHODS OF BLANCHING SNAP BEANS

	Hydraulic Load (l/kkg)	BOD (kg/kkg)	SS (kg/kkg)	Steam Efficiency (%)
Conventional Water	124	0.69	0.13	60
Conventional Steam	125	0.55	0.02	5
Hot-Gas	0.06	<0.01	<0.01	56
Hydrostatic Steam	--	--	--	27
Vibratory Spiral Blancher-Cooler	27	0.53	0.084	85

because it depends on increasingly scarce natural gas or liquified petroleum gas.

Since its effluent is the same as a conventional steam blancher and a cooling flume, the Hydrostatic Steam Blancher makes no reduction in wasteload. Its steam efficiency is a considerable improvement over that of a conventional steam blancher, but it is less than that of a conventional water blancher.

The wasteload for the Vibratory Spiral Blancher-Cooler includes both blanching and cooling, whereas the other wasteloads shown in Table 6 do not include cooling. In preparing vegetables for freezing, flume cooling is generally used after blanching, and flume cooling has a larger hydraulic wasteload than blanching(5). The Vibratory Spiral Blancher-Cooler reduces both of these wasteloads to low levels. If only the Vibratory Spiral Blancher is used, as in canning, then its wasteload would be about the same as that of conventional steam blanching. The Vibratory Spiral Blancher-Cooler has the highest steam efficiency of the blanchers shown in Table 5, thus demonstrating the effectiveness of its seals against steam leaks and its double wall insulated construction.

COST ANALYSIS

Table 7 shows the capital cost of four blanchers. Since conventional steam blanchers are usually custom-fabricated, purchase costs could not be accurately obtained; therefore, it was decided not to include this type of blancher in the cost analysis. Equipment purchase costs are based on equipment manufacturers' price quotations for a capacity of 4.5 kkg/hr (5 tons/hr) of snap beans (2.0 minute blanching time). Other items in estimating direct fixed capital are taken as percentages of equipment purchase cost(12). Floor space is valued at \$270/m^2 (\$25/ft^2). The costs of the water blancher (reel type) and Hot-Gas Blancher include \$5,000 for a flume cooler. The Vibratory Spiral Blancher-Cooler and the Hydrostatic Steam Blancher have the cooler as an integral part of the blancher.

TABLE 7. CAPITAL INVESTMENT FOR BLANCHERS AND COOLERS

	Vibratory Spiral Blancher-Cooler	Water Blancher	Hydrostatic Steam Blancher	Hot-Gas Blancher
1. Equipment purchase cost	$107,587	$16,373	$ 87,446	$126,900
2. Delivery	5,379	819	4,372	6,345
3. Installation	21,517	3,275	17,489	25,380
4. Floor space	4,050	1,719	9,000	25,022
5. Indirect costs	34,633	5,546	29,577	45,873
	$173,166	$27,732	$147,883	$229,520
	1. Equipment Mfg. 2. 5% of 1 3. 20% of 1 4. 15 m^2 at $270/$m^2$ 5. 25% (1+2+3+4)	1. Equipment Mfg. + $5,000 for flume 2. 5% of 1 3. 20% of 1 4. 6.4 m^2 at $270/$m^2$ 5. 25% (1+2+3+4)	1. Equipment Mfg. 2. 5% of 1 3. 20% of 1 4. 33 m^2 at $270/$m^2$ 5. 25% (1+2+3+4)	1. Ralls & Mercer(4) corrected by Marshall and Stevens equipment cost index(12) + $5,000 for flume 2. 5% of 1 3. 20% of 1 4. 93 m^2 at $270/$m^2$ 5. 25% (1++2+3+4)

Table 8 shows the labor, fixed and variable costs for the four blanchers, and it shows the basis used for calculating these costs. Since the open mesh conveyor belts used in the Hydrostatic and Hot-Gas Blanchers probably require more maintenance than the conveying systems used in the Vibratory Spiral or water blancher, higher maintenance costs were used for the former. There are no data available for the wasteload of Hydrostatic Steam Blanchers; therefore, its wastewater cost was calculated from the wasteload of conventional steam blanching with flume cooling (Table 5). The water use and wasteload for flume cooling were added to those of water blanching and Hot-Gas Blanching to get an overall cost of water and wastewater for these systems.

TABLE 8. COST OF BLANCHING AND COOLING FOR FREEZING ($/kkg)

		Vibratory Spiral Blancher-Cooler	Water Blancher	Hydrostatic Steam Blancher	Hot-Gas Blancher
1.	Operating labor	0.63	0.63	0.63	0.63
2.	Supervision, fringes benefits, laboratory, etc.	0.41	0.41	0.41	0.41
3.	Maintenance	0.69	0.11	1.17	1.82
4.	Depreciation	1.37	0.22	1.17	1.82
5.	Insurance, Taxes, other expenses	1.10	0.18	0.94	1.46
6.	Steam	0.68	0.96	2.15	0.77
7.	Electricity	0.04	0.01	0.02	0.36
8.	Water	0.00	0.16	0.17	0.16
9.	Wastewater	0.01	0.15	0.14	0.12
		$4.93	$2.83	$6.80	$7.55

Annual production - 4.5 kkg/hr x 14 hrs/day x 200 days/yr = 12,600 kkg/yr

1. 1/4 man/shift for operation and 1/4 man/shift for cleaning (2 shifts/day) with average hourly wage = $5/hr: 2 (2 + 2) $5/(14 x 4.5) = $0.63/kkg = $0.57/ton.

2. Supervision, fringe benefits, laboratory, supplies, etc. = 65% of operating labor.

3. Maintenance = 5% of direct fixed capital/yr for Vibratory Spiral and water blanchers and 10% of direct fixed capital for Hydrostatic Steam and Hot-Gas blanchers.

4. Depreciation = 10% of direct fixed capital/yr.

5. Insurance, taxes and other fixed expenses = 8% of direct fixed capital/yr.

6. Steam = $4.30/kkg of steam ($1.95/1,000 lb steam). Steam cost for Hot-Gas blancher includes cost of gas ($0.04/kkg).

7. Electricity = $0.014/kw-hr.

8. Water = $0.032/1,000 l ($0.012/1,000 gal).

9. Wastewater = $0.018/1,000 l ($0.062/1,000 gal), $0.022/kg BOD ($0.01/lb BOD), $0.044/kg SS ($0.02/lb SS).

The low capital investment needed for a water blancher is the reason for its low cost of operation. The higher costs of steam, water and wastewater treatment for the water blancher as compared to the Vibratory Spiral Blancher Cooler are not sufficient to compensate for the lower costs associated with capital investment. A nine-fold increase in the cost of steam or a 16-fold increase in wastewater cost would be required to give the Vibratory Spiral Blancher-Cooler a lower operating cost than the water blancher. The Hot-Gas Blancher's high cost is attributable mostly to high capital related costs, while that of the Hydrostatic Steam Blancher is because of steam costs.

No attempt was made in these calculations to account for the loss of vegetable weight when air cooling is used. If frozen vegetables are valued at \$440/kkg (\$0.20/lb), a 2% loss of yield would add the equivalent of \$8.80/kkg to the cost of blanching and cooling. Since frozen vegetables are marketed by weight, such a large penalty for air cooling cannot be economically justified. A change in the way frozen vegetables are marketed would be required to take full advantage of the wastewater reduction possible with air cooling. One should also note that at a price of \$440/kkg for frozen vegetables, the entire cost of blanching and cooling is less than 0.2% of the cost of production. The small impact of blanching and cooling on the total cost of production gives the processor little economic incentive for capital investment in new blanchers.

Table 9 gives a comparison of the cost of the Vibratory Spiral Blancher (without cooler) and the water blancher (without flume) as they would be used for canning vegetables. All other conditions of the cost calculation remain the same. The water blancher still gives the lowest cost of operation, but here a five-fold increase in the combined cost of fuel, water and wastewater cost would make the cost of operating the Vibratory Spiral Blancher about the same as that of the water blancher (A five-fold increase would be equivalent to a 17% annual increase for ten years). By removing the necessity of cooling, the fixed capital investment of the Vibratory Spiral equipment is reduced by 53%, while for the water blancher the removal of the flume reduces the investment by only 28%.

CONCLUSION

Although water blanching has the highest hydraulic waste load, the low capital investment of water blanching makes its cost significantly less than any other blanching technique.

The steam efficiency of the Vibratory Spiral Blancher is higher than other blanchers and, when combined with a Vibratory Spiral Cooler, its wastewater generation is much lower than other blanching techniques except for Hot-Gas Blanching.

Large increases in the cost of energy or wastewater treatment would make the cost of blanching and cooling with the Vibratory Spiral system comparable to that of a water blancher.

Although the Hydrostatic Steam Blancher has a much higher steam efficiency than conventional steam blanchers, its efficiency is still much less than that of a Vibratory Spiral Blancher or a water blancher.

Since frozen vegetables are sold by weight, yield loss from air cooling gives a large economic penalty.

TABLE 9. COST OF BLANCHING WITHOUT COOLING FOR VIBRATORY SPIRAL BLANCHER AND WATER BLANCHER

	Vibratory Spiral Blancher	Water Blancher
	Operating Costs ($/kkg)	
1. Operating labor	0.63	0.63
2. Supervisor, fringe benefits, etc.	0.41	0.41
3. Maintenance	0.33	0.08
4. Depreciation	0.65	0.16
5. Insurance, Taxes, etc.	0.52	0.13
6. Steam	0.68	0.96
7. Electricity	0.01	<0.01
8. Water	0.00	0.01
9. Wastewater	0.02	0.02
	$3.25	$2.41
	Fixed Capital Investment($)	
Purchase Cost	51,000	11,400
Delivery	2,550	570
Installation	10,200	2,280
Floor Space	2,030(1)	1,730
Indirect Costs	16,440	4,000
	$82,220	$19,980

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(1) 7.5m^2

REFERENCES

1. National Canners Association. "Liquid Wastes from Canning and Freezing Fruits and Vegetables," Office of Research and Monitoring, Environmental Protection Agency, Washington, D. C. (1971).

2. Ralls, J. W. and Mercer, W. A. "Low Water Volume Enzyme Deactivation of Vegetables Before Preservation," Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington, D. C. (1973).

3. Lund, D. B. "Wastewater Abatement in Canning Vegetables by IQB Blanching," Office of Research and Development, U. S. Environmental Protection Agency, Washington, D. C. (1974).

4. Ralls, J. W. and Mercer, W. A. "Continuous In-Plant Hot-Gas Blanching of Vegetables," National Environmental Research Center, Office of Research and Development, U. S. Environmental Protection Agency, Corvallis, Oregon (1974).

5. Bomben, J. L., Dietrich, W. C., Hudson, J. S., Hamilton, H. K. and Farkas, D. F. Yields and solids loss in steam blanching, cooling and freezing vegetables. J. Food Sci. 40:660 (1975).

6. Lazar, M. E. and Rasmussen, C. R. Dehydration plant operations. In Food Dehydration, Vol. 2. p. 132. Avi Publishing Co., Westport, Conn. (1964).

7. Bomben, J. L. Unpublished data, USDA Western Regional Research Center, Berkeley, Calif.

8. Perkins, G. Private Communication. Artichoke Industries, Castroville, Calif. (1974).

9. Bomben, J. L., Dietrich, W. C., Hudson, J. S., Durkee, E. L., Rand, R., Farquhar, J. W. and Farkas, D. J. Evaluation of Vibratory Blancher-Cooler for snap beans and lima beans. Proceedings Seventh National Symposium on Food Processing Wastes, Atlanta, Georgia. Industrial Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati (1976).

10. Ray, A. Steam blancher uses 50% less energy. Food Processing 36(1):64 (1975).

11. Layhee, P. Engineered F F line yields 5 big production benefits. Food Engineering 47(2):61 (1975).

12. Peters, M. S. and Timmerhaus, K. D. "Plant Design and Economics for Chemical Engineers," 2nd ed. McGraw-Hill, New York (1968).

DISSOLVED AIR FLOTATION TREATMENT OF SEAFOOD PROCESSING WASTES -- AN ASSESSMENT

by

D.B. Ertz*, J.S. Atwell**, and E.H. Forsht***

INTRODUCTION

Although dissolved air flotation (DAF) has performed well for many years in treating wastewaters of varying characteristics, it has not been as successful to date for seafood processing wastes. DAF with chemical addition, generally considered as primary treatment, represents one of the more sophisticated technologies employed to control wastewaters generated by the United States seafood processing industry. Interest in this physical-chemical process increased shortly after the adoption of PL 92-500 into law which required a reduction of pollutants for all industrial dischargers. Prior to this time, seafood processors which are generally located adjacent to tidal waters discharged process wastewaters with little or no treatment.

Pursuant to the provisions of PL 92-500, the 1977 effluent limitations for the tuna processing segment were based on DAF as the Best Practicable Control Technology Currently Available (BPCTCA). In developing the 1983 requirements, other segments of the industry including the processing of crab, shrimp, salmon, bottom fish, sardine, and herring were assessed with DAF as the Best Available Technology Economically Achievable (BATEA).

As required by PL 92-500, EPA is currently reassessing and updating the promulgated regulations. The Edward C. Jordan Co., Inc., through EPA Contract No. 68-01-3287, is developing the technical information basic to reassessing the effluent limitations and performance standards for the Canned and Preserved Seafood Processing Industry. This paper traces the development of DAF as a viable treatment alternative for seafood processing wastes and presents full-scale operating data from several treatment facilities. It also evaluates current capabilities of the physical-chemical process in light of established design criteria. Solids handling and disposal alternatives are discussed along with the progress of recent investigations concerning DAF and its applicability to other segments of the seafood industry.

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BACKGROUND

The Development Documents (1)(2) which support the promulgated seafood processing effluent guidelines review the applicability and implementation of DAF within the industry. At the time of publication, four significant pilot plant studies (3)(4)(5)(6) had been conducted to determine the effectiveness of this physical-chemical treatment technology. In addition, two full-scale systems were operating; the Canadian demonstration facility at British Columbia Packers, Limited (Steveston, British Columbia) and a DAF unit treating tuna processing wastes at Terminal Island, California. A third DAF unit was installed at a sardine plant in Maine; however, limited information was developed due to mechanical problems.

The Canadian studies (7) conducted during the 1971-2 seasons reported removal efficiencies achieved for various seafood processing wastewaters as listed in Table 1.

TABLE 1. DAF REMOVAL EFFICIENCIES - VARIOUS SPECIES

		Percent Removal		
Species	Chemical Additives	COD	TSS	Oil and Grease
Salmon	Alum and Polymer	84	92	90
Herring		72	74	85
Groundfish		77	86	-
Stickwater		-	95	95

The testing performed on the EIMCO flotator installed at Terminal Island for treating tuna processing effluent was short-term and represented only three trial runs under varying operating conditions. The results of this limited testing program are shown in Table 2.

TABLE 2. DAF REMOVAL EFFICIENCIES
TERMINAL ISLAND - 1972

	Chemical Additive	Parameter	Influent (mg/l)[1]	Percent Removal
Condition A[2]	Sodium Aluminate	COD	2,850	37
	Polymer	TSS	1,170	56
Condition B[3]	Alum	COD	5,100	58
	Polymer	TSS	667	65

1. Thaw water not included
2. Based on two runs
3. Based on one run

The pilot plant study (3) for tuna processing wastes preceded the installation of the full-scale flotator at Terminal Island. Two similar investigations were conducted by the National Marine Fisheries Service which included the treatment of menhaden bailwater (4) and the wastewater from an Alaskan shrimp processor (5). The Gulf Coast shrimp canning study (6) was undertaken by EPA Region VI and a local engineering firm. Presented in Table 3 is a summary of the pollutant reductions achieved in all four investigations. Research efforts concerning the use of DAF for treating seafood processing wastewater realized the importance of chemical additives such as alum and polymers to achieve significant pollutant removals and this concept has been maintained through the design and operation of full-scale systems. In some studies, optimizing pH was a recognized factor for achieving effective operation.

DISSOLVED AIR FLOTATION TREATMENT OF TUNA WASTEWATERS

General

Five tuna processing facilities, three at Terminal Island, California, and two in American Samoa, have been operating DAF treatment systems for more than one year. Facilities in San Diego and Ponce, Puerto Rico, have recently initiated DAF treatment of process wastewaters. An additional system in Puerto Rico is currently in the construction stage.

With the exception of a few demonstration systems operating in other segments of the industry, flotation cells treating tuna processing wastes have been employed as an indicator of the capabilities of dissolved air flotation. NPDES permit monitoring data and additional information collected by the

TABLE 3. SUMMARY OF PILOT PLANT DAF PERFORMANCE

Wastewater Source	Chemical Additive	No. of Samples	Parameter	% Reduction
Tuna	Lime (pH 10–10.5) Polymers Cationic Anionic	1	BOD_5 TSS O&G	65 66 66
Tuna	Lime Ferric Chloride	1	BOD_5 TSS O&G	22 77 81
Menhaden Bailwater	Alum or Acid (pH 5–5.3) Polymer	5	COD TSS O&G	80 87 Near 100
Alaskan Shrimp	Alum Polymer	22	CCD TSS	73 77
Gulf Shrimp	Acid (pH 5) Alum Polymer	5	BOD_5 COD TSS	70 64 83
Gulf Shrimp	Acid (pH 5) Alum Polymer	2	COD TSS O&G	51 68 85

processors have historically provided the basis for technological evaluation. However, much of this information was accumulated using sample collection and analytical techniques which were inconsistent with EPA approved procedures and Standard Methods (8).

To evaluate in-place DAF systems, a field sampling effort was conducted at the Terminal Island facilities. All sample handling and analytical procedures were accomplished in accordance with EPA approved methods.

Description of Terminal Island Facilities

Figure 1 shows a schematic diagram of the wastewater treatment system at the tuna cannery sampled during May 1976, T.I. No. 1. The cannery includes facilities which process fish meal from tuna scrap and non-tuna petfood in addition to canning tuna for human consumption and red meat tuna for petfood.

From the various processing locations, wastewater is pumped to screens (0.030-inch openings) where coarse solids are removed. Equalization of the waste streams is accomplished in the 210,000-gallon surge tank. By throttling the discharge end of a constant speed pump, the equalized wastewater is introduced into the flocculation tank at a controlled flow rate, usually 250 to 1,000 gpm. Approximately 50 mg/l of sodium aluminate is added and mixed in the tank to encourage the formation of flocs.

Following the flocculation process, the flow is then split between two similar flotators (designated as units "A" and "B") which are operated using a pressurized recycle of 20 to 25 percent. Anionic polymer is added to each cell at a 2 mg/l dosage to enhance the removal of suspended solids and oil and grease.

Even though the two flotation cells are identical in structure, the piping and polymer feed arrangements are dissimilar. As shown in Figure 1, the manner in which the pressurized recycle enters the waste stream varies between the two DAF units. For unit "A", the untreated wastewater is fed directly into the cell with the recycle injected perpendicular to the waste stream prior to entering the cell. For unit "B", the pressurized recycle enters the cell directly with the untreated wastewater entering the pressurized recycle stream at right angles. In addition, the polymer is fed directly into the center feed well of the unit "B", whereas polymer for unit "A" is injected at a point just before the waste stream enters the cell.

During low flow periods, the chemical feeds are terminated and fresh water is added to each flotator to inhibit the development of anaerobic conditions. Incoming wastewater is stored and aerated in the surge tank. The treated effluent is discharged to Los Angeles Harbor while the sludge (float) is removed by a skimming mechanism and collected in a holding tank. A centrifuge is available for dewatering the accumulated solids prior to transport to a landfill site by a licensed hauler.

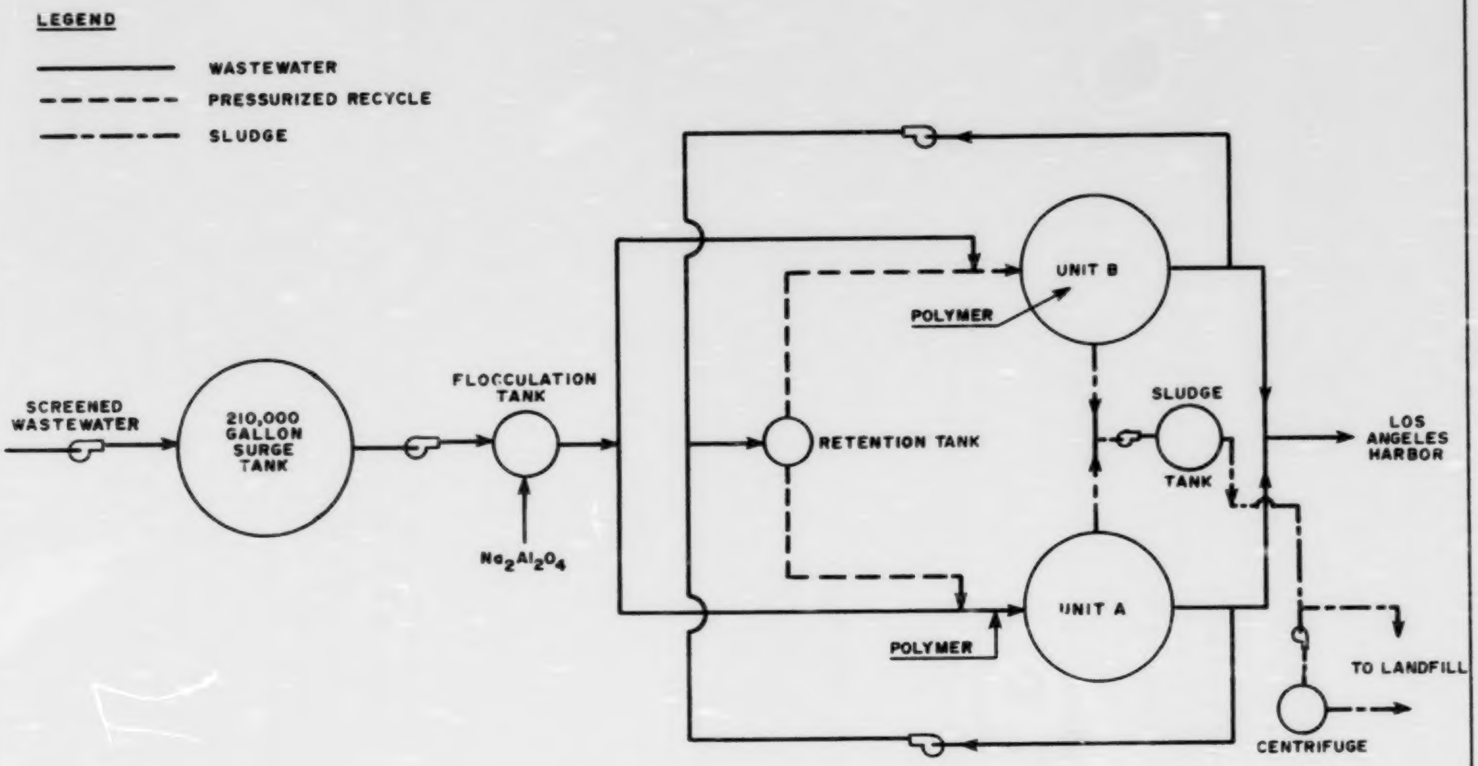
LEGEND
WASTEWATER
PRESSURIZED RECYCLE
SLUDGE
SCREENED WASTEWATER
210,000 GALLON SURGE TANK
FLOCCULATION TANK
$Na_2Al_2O_4$
RETENTION TANK
POLYMER
UNIT B
POLYMER
UNIT A
SLUDGE TANK
LOS ANGELES HARBOR
TO LANDFILL
CENTRIFUGE

FIGURE 1. T.I. NO. 1 DAF TREATMENT SYSTEM SCHEMATIC FLOW DIAGRAM.

At T.I. No. 2, the water pollution control facility, depicted in Figure 2, includes screens (0.020-inch openings), a 300,000-gallon surge tank, and a DAF unit. The wastewater treated at this facility (400-2,000 gpm) is generated during the processing of red meat tuna and non-tuna petfood in addition to canned tuna for human consumption. Process water from tuna scrap reduction is discharged to a separate, but similar treatment system.

Total flow pressurization is employed with the back pressure in the retention tank maintained between 42 and 67 psi in accordance with the flow rate. The desired flow rate is controlled by throttling the pressure control valve and pump discharge valve, and by varying the number of constant speed pumps.

Prior to entering the flotation cell, alum is added to the pressurized waste stream at a feed rate between 40 and 60 mg/l. Approximately 1.0 mg/l of anionic polyelectrolyte is introduced into the center of the cell. Following treatment, the effluent is discharged to the harbor while the float is collected in a storage vessel for loading into a tank truck. The sludge which contains chemical additives is not dewatered with the available centrifuge. Disposal of the material is accomplished at an approved landfill by a licensed hauler.

Terminal Island Sampling Program

Throughout the sampling program, the emphasis was placed on determining the effectiveness of the DAF units operating at both tuna canning facilities. At T.I. No. 1, automatic samplers were employed to obtain hourly aliquots of the DAF influent and effluent on a 24-hour basis. Flow proportioning of the influent samples was not possible; however, it should be noted that the surge tank equalized the flows somewhat and aliquots were not collected during periods when fresh water was added to the flotators. For effluent samples, flow proportioning was accomplished over the entire 24-hour period. During the sampling effort at T.I. No. 2, aliquots were obtained manually for the DAF influent and effluent. A composite was formulated for each sampling point through proportioning the hourly aliquots based on the flow rate through the flotation cell.

Composite samples collected at both wastewater treatment facilities were used in the determination of all analytical parameters with the exception of oil and grease. In compliance with EPA approved methods, four grab samples for oil and grease analysis were randomly obtained. The results of each determination were arithmetically averaged to evaluate the effectiveness of the DAF unit for removing oil and grease.

The sampling program for the Terminal Island tuna canneries consisted of two 10-day sessions. At T.I. No. 1, the effort was conducted during May 1976 while T.I. No. 2 was sampled the following month. Since T.I. No. 1 employs two similar flotation cells with diverse piping and polymer feed arrangements, the effluent for each unit was sampled individually in an effort to determine variations in their performance. The influent, originating from the flocculation tank, is identical for each cell. Over the 10-day sampling

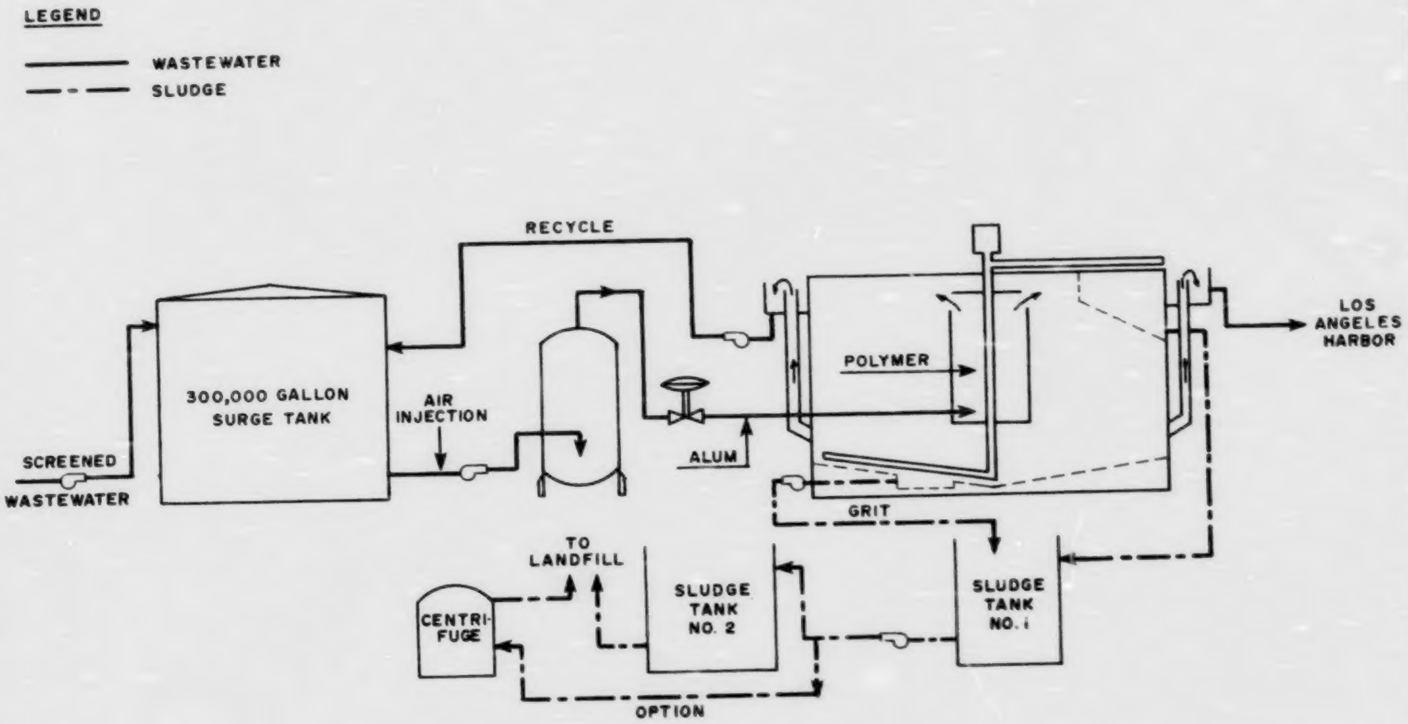
LEGEND
WASTEWATER
SLUDGE
RECYCLE
300,000 GALLON SURGE TANK
SCREENED WASTEWATER
AIR INJECTION
ALUM
POLYMER
LOS ANGELES HARBOR
GRIT
TO LANDFILL
SLUDGE TANK NO. 2
SLUDGE TANK NO. 1
CENTRI-FUGE
OPTION

FIGURE 2. T.I. NO. 2 DAF TREATMENT SYSTEM SCHEMATIC FLOW DIAGRAM.

period, no significant differences were observed in the performance of the units "A" and "B". Verification is provided in Table 4 where the concentrations and percent removals are shown for the various parameters of interest.

TABLE 4. INFLUENT AND EFFLUENT CONCENTRATIONS WITH RESPECTIVE PERCENT REMOVALS FOR DAF UNITS "A" AND "B"
T.I. NO. 1

	Mean		Range	
	mg/1	% Removal	mg/1	% Removal
Influent				
BOD_5	2,563		1,770-5,803	
Total Suspended Solids	1,263		576-2,910	
Oil and Grease	475		267-571	
Unit "A" Effluent				
BOD_5	1,262	45.3	768-1,675	11.0-79.3
Total Suspended Solids	248	76.8	184-320	59.7-90.0
Oil and Grease	81.1	80.7	10.9-267	19.5-98.0
Unit "B" Effluent				
BOD_5	1,374	40.5	550-1,795	4.6-76.6
Total Suspended Solids	282	72.8	108-384	33.3-91.4
Oil and Grease	60.4	86.4	11.2-173	67.1-98.0

The overall removal rates for the treatment system were obtained by averaging the values obtained for each DAF unit. The summarized removal efficiencies for T.I. No. 1 are compared to the projected removals for the tuna industry and BPCTCA as shown in Table 5.

TABLE 5. REMOVAL EFFICIENCIES - T.I. NO. 1

Parameter	Mean	Range	Projected for BPCTCA
BOD_5	42.9%	7.8-77.9%	40%
Total Suspended Solids	74.8%	46.5-89.6%	70%
Oil and Grease	83.5%	43.3-98.0%	85%

As can be seen from Table 5, the removal efficiencies for BOD_5 and total suspended solids observed for the entire DAF system exceeded the projected removals. However, the 10-day average for oil and grease was slightly below the anticipated 85 percent. The operating pH in the flotation cell ranged from 6.4 to 8.7.

During June 1976, a sampling effort was undertaken to evaluate the effectiveness of the T.I. No. 2 water pollution control facility which consisted of one flotation cell. The influent and effluent concentrations quantified over a period of 10 days are summarized in Table 6.

TABLE 6. DAF INFLUENT AND EFFLUENT CONCENTRATIONS - T.I. NO. 2

	Mean (mg/l)	Range (mg/l)
Influent		
BOD_5	883	563 -1,149
Total Suspended Solids	367	306 - 418
Oil and Grease	113	50 - 206
Effluent		
BOD_5	669	339 - 936
Total Suspended Solids	190	132 - 308
Oil and Grease	40.4	4.5- 123

Employing the daily concentrations determined over the duration of the sampling effort, BOD_5, total suspended solids and oil and grease removals were calculated. The effectiveness of the DAF unit in decreasing the mass of pollutants discharged to receiving waters is exhibited in Table 7.

TABLE 7. REMOVAL EFFICIENCIES - T.I. NO. 2

Parameter	Mean	Range	Projected for BPCTCA
BOD_5	24.3%	12.0-47.0%	40%
Total Suspended Solids	48.2%	18.5-62.5%	70%
Oil and Grease	64.3%	0 -96.8%	85%

For each of the three parameters listed in the table above, the observed effectiveness of the wastewater treatment system was significantly less than that projected for the 1977 tuna limitations and the efficiencies documented at T.I. No. 1. The operating pH was slightly more variable, ranging from 6.3 to 9.3.

Since both DAF systems operate in the neutral pH range or slightly above, this cannot be considered as an overriding factor in T.I. No. 1 achieving higher removal rates. It was also observed that the treatment facilities were operated with almost equal proficiency. Therefore, the major consideration was the significant difference between the influent concentrations measured. For each parameter considered, the influent concentrations quantified at T.I. No. 1 were at least three times greater than those observed during the sampling period at T.I. No. 2. Greater pollutant concentrations can be partially attributed to the lower flow ratio, in terms of gallons per ton of tuna processed, maintained by the T.I. No. 1 processing facility. A thaw system which recirculates the water during a specific cycle while injecting steam and adding sulfuric acid has made a substantial contribution in reducing the volume of wastewater requiring treatment. The resulting flow ratio was determined to be an average of 47 percent of that documented at T.I. No. 2.

During the sampling program conducted at the Terminal Island tuna canneries, influent samples were analyzed for soluble BOD_5. A standard method is not available for determining this parameter; however, it is general practice to use the filtrate from the total suspended solids analysis which has passed through 0.45 micron filter paper. The relationship between the soluble portion of the influent BOD_5 as measured and total BOD_5 removal is shown in Figure 3. For this data, the line of best fit was determined through the method of least squares. A fairly good correlation ($r= -0.80$) indicates that as the influent soluble BOD_5 portion increases, the percent total BOD_5 removal decreases. Therefore, minimizing the soluble portion of the influent through pH optimization to the isoelectric point, becomes critical in maintaining consistent BOD_5 removals.

At the present time, the sludge removed from the flotation cells operating at T.I. No. 1 and T.I. No. 2 is landfilled. Samples of this material were collected on a daily basis and subjected to chemical analysis. The results of analysis as it relates to production and flow are shown in Table 8.

TABLE 8. DAF SLUDGE PRODUCTION - T.I. NO. 1 AND T.I. NO. 2

	T.I. No. 1	T.I. No. 2
Volume Ratio (gal/1,000 gal wastewater treated)	19.4	5.5
Average Percent Solids	9.2	15.6
Production Rate - Dry Weight Basis (lb/1,000 lb of tuna processed)	12.1	12.4

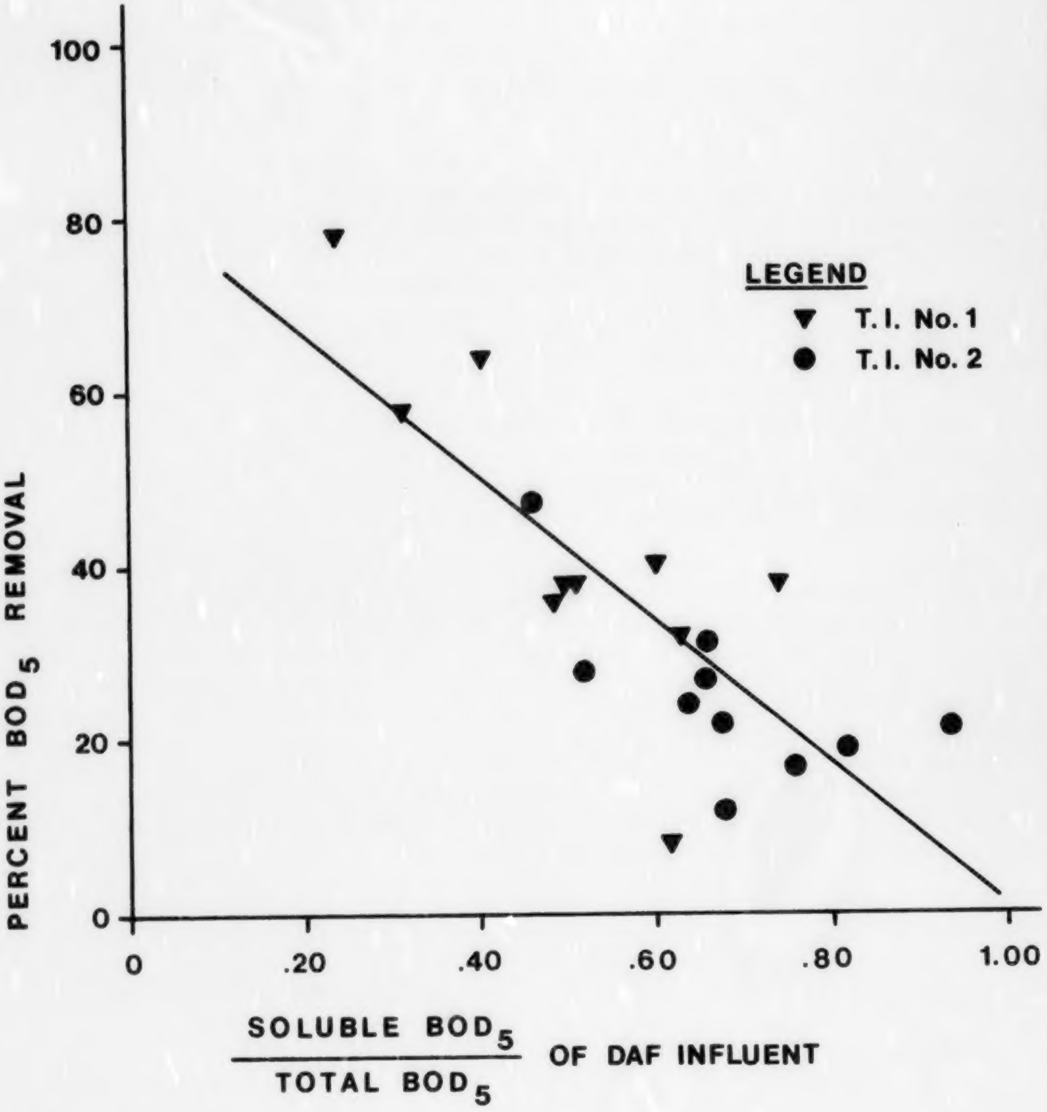

FIGURE 3. PERCENT BOD_5 REMOVAL AS A FUNCTION OF THE SOLUBLE PORTION OF THE INFLUENT BOD_5.

Description of American Samoa Facilities

The tuna canneries in American Samoa operate wastewater treatment facilities which are very similar to the system installed at T.I. No. 2. However, the characteristics of the wastewater generated by A.S. No. 1 and A.S. No. 2 are significantly different. Neither cannery in American Samoa operates a solubles plant, thereby requiring the precook water and presswater to be discharged to the treatment system which results in higher raw waste loads. In addition, petfood production in American Samoa involves red meat tuna only.

Relative to the A.S. No. 1 and A.S. No. 2 wastewater treatment systems, the incoming process flow is screened and subsequently pumped to a surge tank. Following equalization, the total flow is pressurized and chemically conditioned with alum and polymer prior to entering the flotation cell. The treated effluent is discharged to receiving waters while the DAF sludge is collected and hauled to a land disposal site. Solids dewatering is not accomplished at either facility. During periods of low incoming flows, the treatment system at A.S. No. 2 is capable of recycling the effluent to the surge tank as opposed to A.S. No. 1 which is not equipped to operate in this mode.

American Samoa Sampling Program

In August 1976, the EPA National Enforcement Investigation Center (NEIC) conducted a compliance monitoring survey of the two American Samoa canneries (9)(10). The DAF influent and effluent were sampled on a 24-hour basis or during the period of discharge to determine treatment efficiencies at each facility. Effluent aliquots were collected hourly and composited on a flow-weighted basis for BOD_5 and total suspended solids analyses. Samples for influent total suspended solids analysis were composited on an equal-volume basis. During each day, grab samples of the influent and effluent were obtained to determine oil and grease removals. All samples were collected and analyzed as specified by the NEIC chain of custody and analytical quality control procedures.

The NEIC sampling program was conducted during the period of August 18-26. During that time, samples were collected for six 24-hour periods at A.S. No. 1 while the treatment efficiency at the A.S. No. 2 was evaluated based on eight days of data. Due to analytical limitations, influent BOD_5 concentrations were not determined at either facility.

The influent and effluent data collected during the NEIC compliance monitoring survey is summarized in Table 9. It should be noted, however, that the oil and grease analysis of the DAF influent was performed on four of the six sampling days.

TABLE 9. DAF INFLUENT AND EFFLUENT CONCENTRATIONS - A.S. NO. 1

	Mean (mg/l)	Range (mg/l)
Influent		
BOD_5	-	-
Total Suspended Solids	4,880	2,700-13,100
Oil and Grease	1,500	1,080-2,770*
Effluent		
BOD_5	2,480	1,500-3,900
Total Suspended Solids	220	70-620
Oil and Grease	120	26-340

*Oil and grease concentration of 2,770 mg/l is based on one grab sample and not the normal averaging of 3-4 grab samples.

The ability of the treatment system to remove constituents from tuna processing wastewater is measured in terms of removal efficiencies. Using the respective concentrations for total suspended solids and oil and grease, the appropriate removal rates were determined as shown in Table 10.

TABLE 10. REMOVAL EFFICIENCIES - A.S. NO. 1

Parameter	Mean	Range	Projected for BPCTCA
BOD_5	-	-	40%
Total Suspended Solids	95%	94-98%	70%
Oil and Grease	88%	64-99%	85%

The removal efficiencies for both parameters substantially exceeded the removals projected in developing the BPCTCA guidelines for the canned tuna industry. The operating pH of the flotator ranged from 4.2-6.5, approaching the isoelectric point for fish protein (4.5-5.0).

Employing a similar method for A.S. No. 2, monitoring data collected for a total of eight days can be summarized. In Table 11, the characteristics of the wastewater treated by the DAF unit and the resulting effluent are presented.

TABLE 11. DAF INFLUENT AND EFFLUENT CONCENTRATIONS - A.S. NO. 2

	Mean (mg/l)	Range (mg/l)
Influent		
BOD_5	-	-
Total Suspended Solids	860	520-1,100
Oil and Grease	540	87-730
Effluent		
BOD_5	970	820-1,120
Total Suspended Solids	290	60-510
Oil and Grease	230	18-280

To evaluate the effectiveness of the single flotation cell over the sampling period, a comparison can be made between the removals achieved at A.S. No. 2 and the 1977 levels. This is accomplished in the data summary presented in Table 12.

TABLE 12. REMOVAL EFFICIENCIES - A.S. NO. 2

Parameter	Mean	Range	Projected for BPCTCA
BOD_5	-	-	40%
Total Suspended Solids	66%	23-93%	70%
Oil and Grease	57%	33-97%	85%

Although BOD_5 removals were not monitored, it appears that the A.S. No. 2 treatment system is operating well below the desired levels. The operating pH which is critical to the performance of the physical-chemical process was maintained within a range of 5.9-7.4, considerably higher than the isoelectric point of fish protein.

The DAF system with the addition of alum and polymer operating at A.S. No. 1, achieved significantly greater removal efficiencies than the A.S. No. 2 facility in addition to exceeding the projected removals for 1977 or best practicable treatment. In evaluating the performance of the two facilities, the higher removal rates observed at A.S. No. 1 can be attributed, in part, to a lower operating pH range within the flotator. In addition, the greater influent concentrations can provide a basis for better performance while actual operation of the two systems also demands consideration. As documented by NEIC, operating personnel at A.S. No. 1 were attentive and appeared to have a better understanding of the treatment process. The flow rate was maintained relatively constant throughout the day. An evaluation of the design of the two wastewater treatment systems by NEIC concluded that the A.S. No. 2 DAF unit is overdesigned for the flow undergoing treatment.

Similar to the T.I. No. 1 facility, influent concentrations for total suspended solids and oil and grease measured at A.S. No. 1 exceeded those observed at A.S. No. 2 by more than 300 percent. Effluent BOD_5 values were also significantly greater at A.S. No. 1. Recirculated thaw water with sulfuric acid addition produced lower flow ratios (approximately 50 percent of A.S. No. 2), increased influent waste loads, and depressed the pH of the wastewater subjected to treatment.

RECENT INVESTIGATIONS

Treatment technologies more sophisticated than screening are not required for the remaining segments of the seafood industry until the implementation of 1983 limitations. Therefore, investigations of DAF involving wastewater generated during the processing of other commodities to date have not been extensive.

On a pilot scale, the National Marine Fisheries Service has evaluated the application of air flotation to treat the effluent from a cannery in the Puget Sound area which processes salmon and tuna. The treatment system included screening (20-mesh) followed by a wastewater concentrator with a 165-mesh or 400-mesh screen. During the concentration process, air is entrained into the waste stream which is subsequently released within a flotation cell placed in series with the concentrator. This scheme is essentially a dispersed air flotation system with alum and lime added upstream of the concentrator and polymer assisting in the flotation process. The pH in the cell was maintained in the 8.0-10.0 range as opposed to the isoelectric point of fish protein.

Additional information is currently being developed in Louisiana through an EPA demonstration study. A full-scale DAF unit has been employed for the treatment of shrimp canning wastes as well as the wastewater produced from the oyster canning operation at the same processing facility. Further investigations will be conducted during the 1977 shrimp canning season.

SOLIDS HANDLING AND DISPOSAL ALTERNATIVES

During the initial assessment of waste management within the seafood industry, byproduct recovery was emphasized. In-plant controls to prevent product related materials from entering the waste stream were thought to be an integral part of the total waste management program. Incorporating solids which are produced from the implementation of wastewater treatment technologies, including screens and DAF, into a saleable product was given consideration as a viable alternative for ultimate disposal.

To minimize handling costs, sludge generated from relatively large scale wastewater treatment systems should be concentrated prior to further processing or final disposal. Flotation sludge produced during the treatment of wastewater containing fats and oils of animal origin can be difficult to dewater. Currently, one facility which dewaters the DAF float generated from treating seafood processing wastes has been identified. In this particular case, a centrifuge has proven successful in substantially reducing the moisture content of the sludge accumulated from a DAF system operating within the tuna industry.

To determine current practices of industries producing sludge with characteristics similar to that experienced by tuna processors, a survey of meat packers, poultry processers and renderers was conducted. Emphasis was placed on identifying dewatering methods other than decanting and processors rendering sludge which contains chemical coagulants such as alum and polymers.

A total of 40 processors employing DAF to treat their wastewaters were contacted to discuss methods of float handling and disposal. The results of the survey are summarized in Table 13.

TABLE 13. DAF FLOAT HANDLING AND DISPOSAL FOR RELATED INDUSTRIES

	Red Meat	Poultry	Renderer
Total Number Surveyed	20	10	10
Render	12	7	10
Chemical Additives + Render	5	2	9
Chemical Additives + Dewater + Render	2	0	0
Land Disposal	5	2	0
Other	3	1	0

Only two red meat processors reduced the moisture content of the sludge through mechanical means, which was identified as centrifugation. Gravity settling with subsequent decanting was found to be the most common dewatering method with 15 processors employing this alternative. In some instances, the sludge was heated to encourage liquid-solids separation; however, this is generally employed in conjunction with in-house byproduct recovery operations such as rendering. Slightly more than half of the facilities contacted did not concentrate the float to yield a greater solids content prior to further processing or ultimate disposal.

Approximately two-thirds of the facilities operating DAF units rendered the float in-house or hauled it to an off-site rendering operation. As one would expect, all renderers reintroduced their residuals into their operations; while nine of ten employed chemicals to aid removals. Seven of the eleven meat packers and poultry processors using coagulants subsequently subjected the recovered solids to a rendering operation.

The results of this survey are by no means conclusive relative to the ability of the seafood industry to recover DAF sludge and incorporate it into a useful byproduct. It does appear that rendering sludge containing chemical coagulants is feasible, reinforced by the current practices of other food related industries. However, further investigation is required to determine its applicability to the seafood processing industry. At the present time, the major considerations include the effect of chemicals on the quality of the rendered product as well as the economics of operating this type of byproduct facility.

SUMMARY

In general, the seafood processing industry can be considered relatively unsophisticated with regard to treating its process wastewaters. Much of the industry provides either screening or no treatment before discharging to inland or tidal waters. Prior to July 1, 1977, measures must be implemented to provide coarse solids removal with the equivalent of 20-mesh screens. However, tuna processors which are generally large volume producers with a somewhat consistent supply of raw material have been mandated to meet more restrictive limitations based on DAF. The larger tuna canners located in Terminal Island and American Samoa and most recently those in San Diego and Puerto Rico have become the forerunners with respect to dissolved air flotation treatment on an industrial level for the entire seafood industry.

The capability of any treatment system is first dependent on the design and secondly, actual operation. Based on the operating data presented herein, the facilities monitored meet the generally accepted design criteria and in some cases fall on the conservative side. When evaluating DAF in light of industrial waste treatment, the criteria of concern are overflow rate, solids loading, air to solids ratio, hydraulic retention time and the ability to maintain the appropriate pH level. During previous investigations, it has been shown that the design criteria outlined in Table 14 will provide acceptable results. The pH for effective chemical coagulation of a proteinaceous waste is optimal at the isoelectric point which for fish processing wastes falls into the 4.5-5.0 range. In addition, the treatment system should be designed to optimize flocculation of suspended solids with the correct chemical dosages determined for the specific wastewater to be treated. Incorporating flexibility and ease of operation into the final design is also a necessity.

TABLE 14. DAF DESIGN CRITERIA FOR SEAFOOD PROCESSING WASTES

Overflow Rate	2 gpm/sq ft
Solids Loading	1 lb/hour/sq ft
Air to Solids Ratio	0.01-0.04
Hydraulic Retention Time	1 hour

With a well-designed system, the capabilities of the water pollution control facility relies heavily on the operator and his working knowledge of the treatment process. In other words, operation is the key to successful wastewater treatment whether it is an industrial or municipal facility. With regard to industrial wastewater treatment, in-plant measures to reduce water consumption and concentrate individual waste streams gains importance. These concepts are borne out when considering the American Samoa DAF system which achieved the best removal efficiencies. A lower flow ratio for an adequately designed system, in conjunction with an attentive operator and a pH close to the desired range, produced excellent removals for suspended solids and oil and grease.

It should be realized that data collected at the four tuna canneries was summarized from information accumulated over a period which ranged from 6 to 10 days at each facility. In reviewing the monitoring data, two of the canneries equalled or exceeded the removal efficiencies for total suspended solids and oil and grease which were projected in developing the 1977 limitations. However, the level of consistent BOD_5 removal for tuna processing wastewater has not been documented conclusively. The processing of non-tuna petfood at Terminal Island, where extensive BOD_5 data was collected, creates some uncertainty. The soluble portion of BOD_5 remains a critical factor with increased removal rates being achievable through good operation and by maintaining the optimal pH range. Further optimization will be required to achieve the more restrictive 1983 limitations.

As operating experience increases and additional information develops at these and other facilities within the tuna industry, the capabilities of DAF will be more fully realized. This information will become the basis for subsequent comparisons relative to the removals necessary to meet the 1977 limitations as well as those for BATEA in 1983. Operating data for tuna wastewater treatment will be further supported by information developed through subsequent pilot plant investigations and ongoing full-scale demonstration studies.

For the most part, the handling and disposal of residuals produced by DAF is considered to be a difficult problem by the seafood processing industry. Information has been presented outlining the approach other industries have taken. While some meat processors are dewatering float through mechanical devices, a greater number incorporate this material which contains chemical additives into byproducts. Of prime concern is the value of the processed material and the ability to meet acceptable specifications for certain products. One tuna processor has found the means to successfully dewater residuals by centrifugation; however, byproduct recovery from this material has not been implemented on a full-scale basis. The economics of solids disposal requires further investigation with viable alternatives developed, especially for those segments of the seafood industry which experience more seasonability and higher variability with raw material supply than the tuna processors.

REFERENCES

1. Development Document for Effluent Limitations and Guidelines and Standards of Performance for the Catfish, Crab, Shrimp, and Tuna Segment of the Canned and Preserved Seafood Processing Industry, Point Source Category, U.S. Environmental Protection Agency. Washington, DC 20460, June 1974.

2. Development Document for Effluent Limitations Guidelines and Standards of Performance for Fish Meal, Salmon, Bottom Fish, Clam, Oyster, Sardine, Scallop, Herring and Abalone Segment of the Canned and Preserved Seafood Processing Industry, Point Source Category, U.S. Environmental Protection Agency, Washington, DC 20460, September 1975.

3. Jacobs Engineering Company, "Pollution Abatement Study for the Tuna Research Foundation, Inc.," 1971.

4. Baker, D.W. and C.J. Carlson, "Dissolved Air Flotation Treatment of Menhaden Bailwater," *Proceedings of the 17th Annual Atlantic Fisheries Technology Conference (AFTC)*, Annapolis, Maryland, 1972.

5. Peterson, P.L., *Treatment of Shellfish Processing Wastewater by Dissolved Air Flotation*, Unpublished Report, Seattle: National Marine Fisheries Services, U.S.D.C. 1973.

6. Mauldin, A.F. and A.J. Szabo, *Shrimp Canning Waste Treatment Study*, Project S 800904, Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington, DC 20460, 1974.

7. Claggett, F.G., *Clarification of Fish Processing Effluents by Chemical Treatment and Air Flotation, Technical Report No. 343*, Fisheries Research Board of Canada, 1972.

8. *Standard Methods for the Examination of Water and Wastewater*, 14th Edition, American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC, 1975.

9. "Compliance Monitoring and Wastewater Treatment Evaluation, Van Camp Sea Food Company, Pago Pago, American Samoa," EPA-330/2-76-035, Office of Enforcement, U.S. Environmental Protection Agency, December 1976.

10. "Compliance Monitoring and Wastewater Treatment Evaluation, Star-Kist Samoa, Inc., Pago Pago, American Samoa," EPA-330/2-76-036, Office of Enforcement, U.S. Environmental Protection Agency, December 1976.

COMMERCIAL FEASIBILITY OF RECOVERING TOMATO PEELING RESIDUALS

by

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ABSTRACT

In the United States, tomatoes are peeled for canning by first immersing in a caustic bath to loosen the skin; then, the peel is removed either mechanically with rubber discs or with water sprays. When the peel is removed mechanically, the peel solids are not diluted and therefore are similar to the pulp of whole tomatoes. Since this removed peel is at least 12% of the unpeeled weight and the peel is about 96% pulp, this peel pulp is a potential source of food material. It also is attractive economically because there is a possible pulp recovery value of $230/hr from a typical 40-t/hr peeling operation; processing this material would cost about $188/hr the first year and $43/hr thereafter, leaving a $187/hr net return in the second and subsequent years. A two-year project was undertaken and funded jointly by USDA-WRRC, NCA, EPA, and the California tomato processors. In 1975 peel from regular cannery operations was processed through a 20-gpm (5t/hr) continuous-flow line. This processing consisted of acidifying the peel to pH 4.2 with food-grade hydrochloric acid, then separating the pulp from the skin with a paddle finisher. Recovered peel pulp was found to be of food quality, but contained high peeling-aid residues (150-450 ppm). Practically all tomato peeling operations use a peeling aid in the caustic bath to facilitate uniform peeling, particularly on the shoulder of the tomato. Peeling aids in current use are approved for peeling but not as additives to the final product. In 1976, a 1-t/hr pilot peeling line was set up at a cannery to study modifications in the peeling process. The purpose of the modification was to pretreat the tomatoes by immersion in a 150 F aqueous bath (pH 3.6) containing about 0.15% food-grade octanoic acid. Recovered pulp could meet USDA Quality Grade A, and the octanoic acid levels were low, about 30 ppm. Discussions are being held with FDA on several aspects because the proposed use of this recovered peel pulp is in combination with tomato pulp from regular sources for canned products, such as tomato sauce, puree, catsup, paste, and fill juice for peeled tomatoes. The compositions of these products are governed by the FDA Standards of Identity.

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INTRODUCTION

In the United States, tomatoes are normally peeled by loosening the skin with a hot-caustic bath and removing the peel (skin with adhering pulp) either mechanically with rubber discs or with water sprays. The use of water sprays has declined because of the large amount of water needed (500-1500 gal/t) and the subsequent problem of waste disposal of the dilute solution. Removal of the peel mechanically with rubber discs reduces the water consumption to a negligible amount so that the peel has about the same solids content as fresh tomatoes. This material is currently discarded as solid waste. Peel removed that is recoverable constitutes at least 12% of the original tomato weight. Since this peel is about 96% pulp, it is a potential source of food material. This pulp is also attractive economically because there is a potential net pulp worth of $187/hr for a typical 40 t/hr peeling operation based on a raw material value of $50/t. There are about 1.3 million tons of tomatoes peeled each year in the United States, resulting in at least 150,000 t/yr of recoverable pulp. Currently that pulp is discarded as peel at an expense of $2.50 to $5.00/t, or as much as $750,000/yr for the peeling industry. Despite the economic incentive, there were several technical obstacles such as insecticide residues, the lye and surfactants from the caustic-peeling applicator, acidification of the alkaline peel, recovered-pulp quality, product labeling, etc. With these potentials and obstacles in mind, a two-year project, beginning in 1975, was undertaken jointly by the USDA Western Regional Research Center, National Canners Association Western Research Laboratory, and the tomato processing industry. The initial plans were described in April 1975 (1) and were based on trends in commercial practice and prior information on pulp recovery potential (2) (3) (4) (5). Experimentation was implemented during the 1975 tomato processing season. The 1976 work was to develop methods to answer the problems discovered in 1975.

METHODS

1975 Experimentation--Peel Processing & Pulp Characterization

Peel was experimentally processed on a daily basis during 1975 as received from conventional caustic peeling at the Tillie Lewis Foods, Plant W, Antioch, California. This cannery processed VF-145 tomatoes through washing and sorting, then about 40 t/hr were diverted to their peeling operation. The diverted tomatoes were next immersed in a caustic bath; this was a typical industrial situation using 10-12% (w/w) sodium hydroxide with up to 0.2% sodium 2-ethylhexyl sulfate at 200-210°F and a nominal half-minute immersion. From this bath the tomatoes went into two types of mechanical peel removers, a flat-bed disc type followed by peel-tag removal rolls (FMC PR-20 Tomato Peel Remover, 1 machine) and rotary-cylinder, rubber disc types (Magnuson Model C Peel Scrubbers, 4 machines). All of these peel removers fed into a common pump which sent the peel to the experimental peel-pulp recovery area. This peel, from the normal cannery peeling, was received about 5 minutes after the clean tomatoes first entered the caustic applicators.

Figure 1 shows the 1975 experimental equipment layout, and Figure 2 is a diagram of the pertinent operations for both the conventional and the experimental processing. The primary variables were: (1) the extractor screen size and paddle clearance, (2) place of acidification, (3) hot-break temperature, (4) lag time between the hot break and canning, (5) evaporator temperature and degree of pulp-solids concentration, and (6) the heat-processing time of cans. These variables were evaluated in terms of: (1) pulp yield, (2) product quality, and (3) tomato Standards of Identity.

Peel was received continuously at 10-30 gpm, and acidified with food-grade hydrochloric acid either immediately in the Peel Tank or later in the Hot-Break Vessel; this acidification was continuously controlled by an automatic pH recording controller. The Peel Tank volume was 48 gal. and the Hot-Break Vessel was 250 gal. Peel flowed continuously into each of these vessels and constant volumes were held by overflow weirs.

From the Peel Tank, the peel flowed into the Extractor which was used to separate the pulp from the skin, seeds, and fibers; seeds and fibers are present from tomatoes that disintegrate during peel removal. This Extractor was a standard FMC Model 50 Pulper with a 0.030-in. screen and set with a 0.5-in. screen-paddle clearance.

A Hot-Break Vessel was provided to inactivate enzymes that might be present, to reduce subsequent microbiological growth if the incoming pulp was to be held at the projected incoming pulp temperature of 120 F for an extended period. It also provided thermal-exposure testing since caustic exposed tomato pulp is more susceptible to color and flavor changes.

Next the pulp flowed into the Pulp Tank for a final check and recording of pH. A material (mass) balance was made for each trial by weighing the Extractor waste and measuring the volume of the recovered pulp. Recovery was determined with 400-1,000 gal. batches; the weight of the recovered pulp and Extractor waste was equal to that of the incoming peel. Recovered peel pulp was concentrated in 1,000 gal. batches at 160-200° F to concentrations of 10-20% TS (total solids) in the cannery single-stage vacuum evaporator.

Both fresh and canned samples were made up for subsequent analyses. All canned samples were hand filled into size 211 x 400 unenameled cans, sealed with a double seamer, heat processed in boiling water for 40 minutes, and cooled to 100°F in 75°F water. These canned samples were analyzed and judged on a 100% recovered-pulp basis without blending with other tomato materials.

1976 Experimentation--Pilot Scale Modified Caustic Peeling

The 1976 experimentation was primarily directed towards solving the peeling-aid residue problem which was identified during the 1975 pulp recovery experimentation. This development was carried out during the spring laboratory-peeling tests and the summer cannery pilot-peeling tests. In the spring, laboratory peeling was conducted on tomatoes using a wide

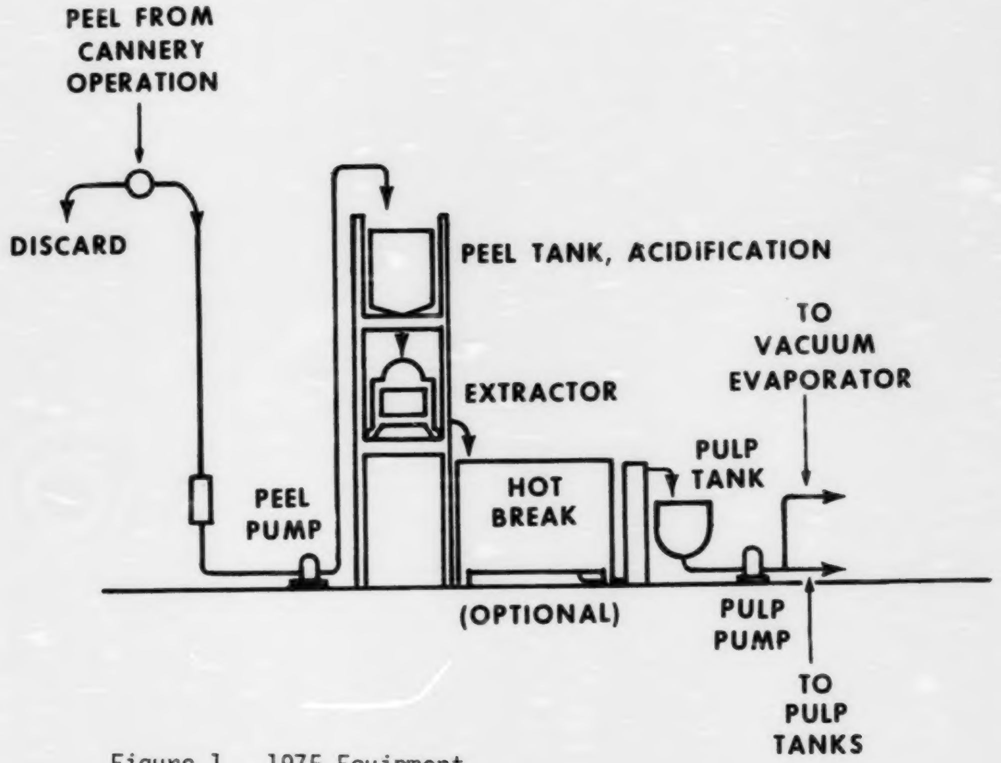

PEEL FROM
CANNERY
OPERATION
DISCARD
PEEL TANK, ACIDIFICATION
TO
VACUUM
EVAPORATOR
EXTRACTOR
PULP
TANK
HOT
BREAK
PEEL
PUMP
(OPTIONAL)
PULP
PUMP
TO
PULP
TANKS

Figure 1. 1975 Equipment.

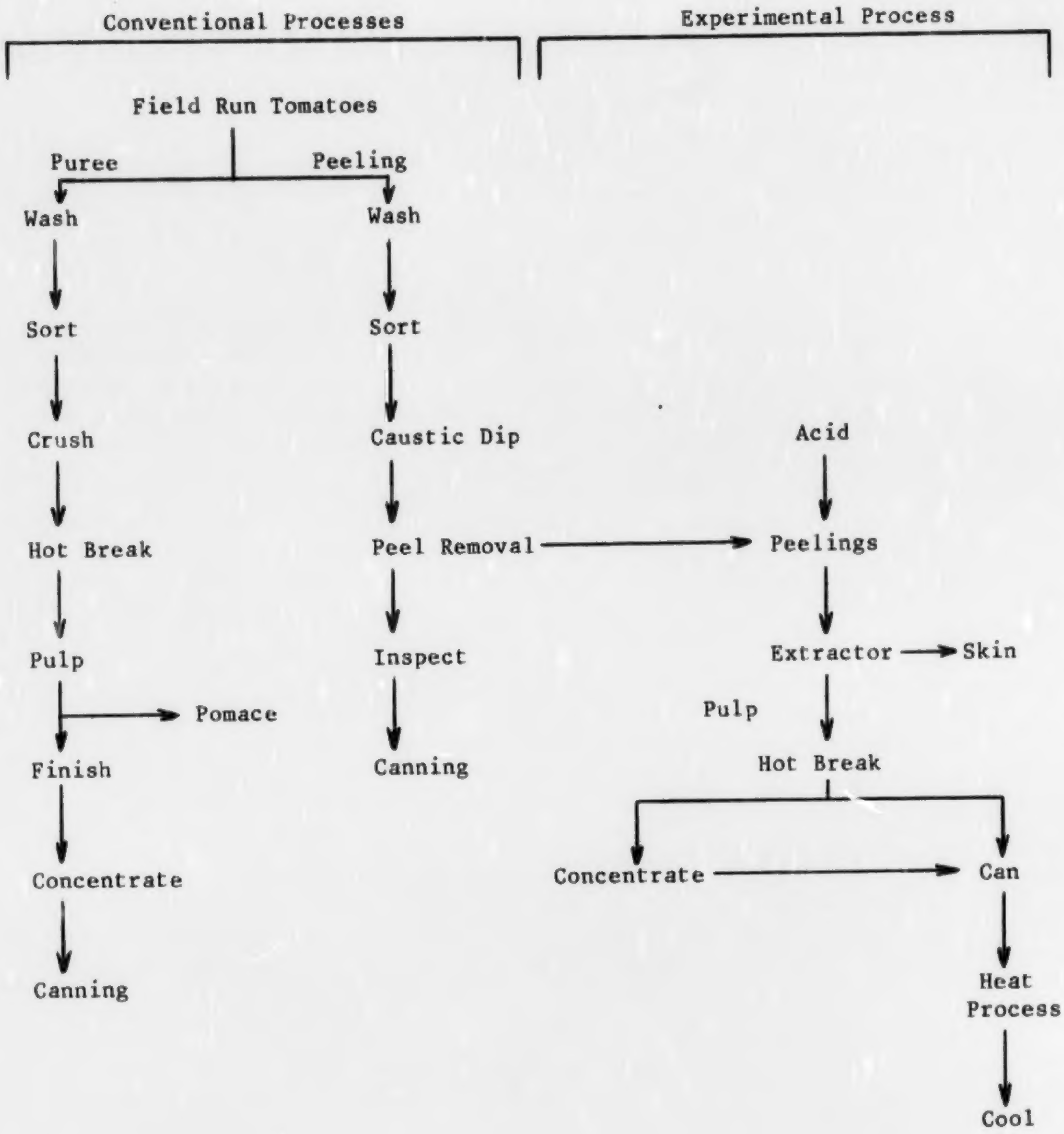
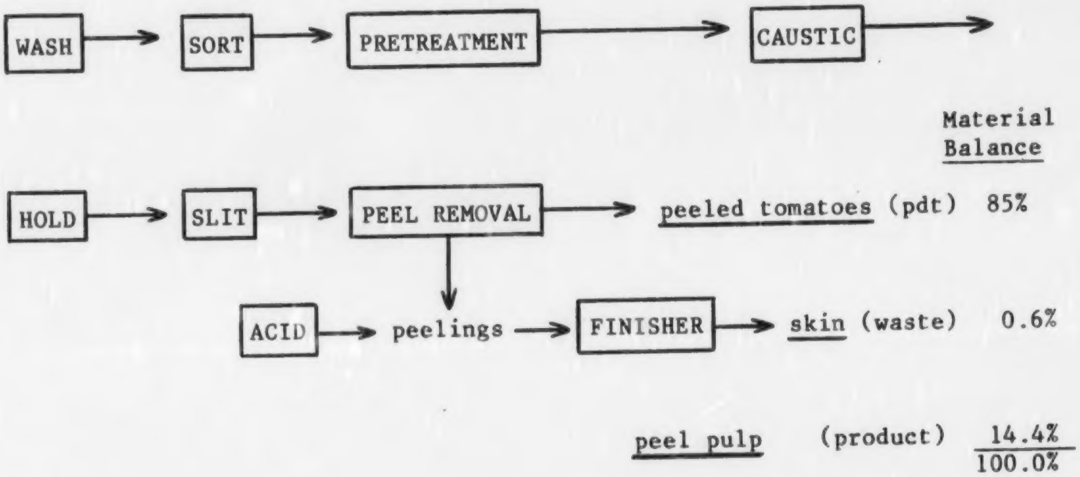

Conventional Processes
Experimental Process
Field Run Tomatoes
Puree
Peeling
Wash
Sort
Crush
Hot Break
Pulp
Pomace
Finish
Concentrate
Canning
Wash
Sort
Caustic Dip
Peel Removal
Inspect
Canning
Acid
Peelings
Extractor
Skin
Pulp
Hot Break
Concentrate
Can
Heat Process
Cool

Figure 2. 1975 Flow Diagram.

range (about 70) of compounds including many surfactants (surface active agents) to determine the chemical structure that aided peeling. The wetting action (interfacial tension) of the potential peeling aids was checked, and this surface-wetting action was found to provide little assistance in selecting peeling aids because much of their real benefit seems to be in chemical activity. Potential peeling aids were applied in two ways: (1) directly in the caustic bath in the traditional manner, and (2) as a pretreatment prior to immersing the tomatoes in the caustic bath; these were compared to peeling with a plain caustic bath. The purpose of the pretreatment was to apply only enough peeling aid to permeate the skin as needed to aid peeling or to allow the caustic to act more effectively in the applicator. It was also assumed that the optimum temperature and time for applying the peeling aid might differ from those existing in the caustic applicator. The best conditions found in the laboratory peeling tests were incorporated in a 1-t/hr pilot-peeling line at Hunt-Wesson Foods, Plant A, Hayward, California during the 1976 tomato processing season. This line operated with the regular cannery tomatoes, usually Variety UC- 134. Washing, sorting, and pretreatment was carried out solely on the pilot equipment. Typical operating conditions and equipment are shown in Figure 3. Peeling was performed continuously, typically in 45 minute runs. Since there was insufficient peel flow from this pilot line to continuously acidify the peel, acidification was performed batchwise at about 4-5 min. intervals. Extraction of skin and pulp was done at the end of each run.

This cannery received tomatoes usually in bulk 20-t loads (truck and trailer) as is typical for California canners. The tomatoes were removed from the trucks by the cannery personnel through a water wash-out and carried by a flume into a sump; from the sump they were elevated out and spray washed, passed over a screen to remove gross trash and tomatoes less than 1.2-in. in diameter and then flumed on to further rinsing and hand sorting. From this flume, prior to further cannery washing and sorting, part of the tomatoes were diverted to the pilot-peeling line. These tomatoes were immersed in water, elevated out, and passed over a 1-ft x 10-ft rubber disc flat-bed scrubber having water sprays; this was the final washing. The tomatoes were then passed over a sorting belt for hand sorting; the degree of hand sorting was varied so as to compare mold counts in the recovered pulp. The pretreatment immersion was in a 17-in. x 10-ft trough having a paddle-type conveyor which carried the tomatoes through in positive displacement fashion. The heated solution was recirculated from entry to exit at about 20-gpm, and was controlled and varied from 75°F to 200°F, depending on the experiment. Immersion time could be varied from 15 seconds to three minutes. From this pretreatment, the tomatoes were removed on an open-mesh elevator for a variable draining time of 10 seconds to 2 minutes. After draining, the tomatoes dropped into the Caustic Applicator for 10-sec. to 2-min. immersion in 11% (w/w) sodium hydroxide at 210°F. An applicator such as the commercial FMC Hi-Ton Tomato Peeler has a drain period of about 50% of the immersion time, which not only removes excess caustic solution but provides a further period for the caustic to act on the tomato. The pilot applicator did not have a similar drain period so this was simulated by a variable-speed, open-mesh belt normally held to 0.18-min. residence time. Tomatoes then passed over rotating slitting blades


WASH
SORT
PRETREATMENT
CAUSTIC
Material Balance
HOLD
SLIT
PEEL REMOVAL
peeled tomatoes (pdt) 85%
ACID
peelings
FINISHER
skin (waste) 0.6%
peel pulp (product) 14.4%
100.0%

Nominal Conditions

Tomatoes: Variety 134, field run,

Washing: 1st and 2nd by water immersion; 3rd by flat-bed rubber discs wih spray rinse.

Sorting: hand.

Pretreatment: 0.5 min., 150°F, 0.15% w/w octanoic acid.
0.5 min. drain on elevator.

Caustic Applicator: 0.5 min., 200°F, 11% w/w sodium hydroxide.

Drain & Hold: 0.18 min.

Slitter: rotating knives.

Peel Removal: Flat-bed, rubber discs.

Acidification: (whole) peel with hydrochloric acid.

Peel-pulp & Skin Separation: paddle pulper with 0.030-in. screen and 0.5-in. clearance.

Figure 3. 1976 Pilot Peeling.

and onto a 12 -in. x 10-ft set of flat-bed rubber-disc peel removers which were operated without water sprays so as not to dilute the peel. This dry removal of peel is increasingly being practiced commercially. Peel dropped onto a full-length pan, flowed down to a 10-gal. pot, where the peel was acidified with hydrochloric acid to pH 4.2 ± 0.2. This acidified peel was separated into skin and pulp fractions with a Langsenkamp Indiana Laboratory Pulper equipped with a 0.030-in. screen. This recovered pulp was canned in 211 x 400 enameled containers, processed for 45 minutes in boiling water, and cooled to about 100°F in 75°F water. For a material balance on each trial, both the recovered pulp and peeled tomatoes were weighed, typically 1,000 to 2,000 lbs/trial.

Analyses

The analytical methods used in 1975 and 1976 are listed in the Bibliography, Analytical Procedures. In addition, all canned recovered pulps were graded by the USDA Agricultural Marketing Service using the same U.S. Grade Standards for Canned Tomato Pulp as for regular commercial products. The fatty acids were analyzed by a solvent extraction, esterification, and GLC detection method which is currently undergoing further refinements.

RESULTS & DISCUSSION

While the overall 1975 results (Table 1) showed there is food potential in recovering pulp from caustic tomato peelings, there was one major detractant--the peeling aid residue at 150-450 ppm. Of the currently used commercial peeling aids (sodium 2-ethylhexyl sulfate, sodium mono- and di-methyl naphthalene sulfonates, or fatty-acid mixtures which contain predominantely odd-numbered carbons), none seemed suitable for clearance as food additives. Even if an additive-grade peeling aid was currently available, the 150-450 ppm residue is large enough to raise questions as to whether it would need to be declared on the product label as an intentional additive. These questions on the peeling aid determined the direction of the 1976 work, the second and final scheduled year of the project. While it is possible to peel tomatoes without a peeling aid, it is generally acknowledged that higher caustic concentration and temperature are required; these lead to higher peel loss, and as a result the peeled tomato quality suffers since the vascular veins become more pronounced. If a peeling aid is used in the caustic, the residue level possibly could be reduced to less than found in 1975, but it was assumed to be impractical to reduce the residue to zero. Therefore, means were developed in 1976 to minimize peeling-aid residues by using potential food-additives as peeling aids.

In normal cannery operations, the juice and pulp supplies are interconnected so that these materials can be shunted among the different sources and utilization points to satisfy changing production requirements. Therefore, in actual cannery practice recovered peel pulp would be combined with juice and macerate from other sources before processing into standard products such as tomato sauce, catsup, fill juice for whole-canned tomatoes, or other salted products. During acidification and possibly at the rubber-disc peel removal point, a small amount of water will be incorporated in the peel. This

TABLE 1. SUMMARY OF TYPICAL 1975-1976 RECOVERED PEEL PULPS

	Typical Single-Strength Tomato Pulps		
	1975	1976	Conventional Processing (a)
Recovery of peel (w/w)%	96.7%	95%	n/a
NTSS, (natural tomato soluble solids), %w/w	5.3	5.2	5.4%
Salt, (sodium chloride), g/100 gm	3.-	1.1	0.08
Total Solids, (salt free), % w/w	5.6	5.9	5.71
Vitamin A, (beta-carotene), I.U./100 gm	665	---(b)	516
Vitamin C, (ascorbic acid), mg/100 gm	nil	nil	10.7
Color Grade, (as puree)	A-C	A	A
Flavor Grade, (as puree)	C	A-C	A
Peeling Aid residue, pulp. ppm (c)	300	30	0 (d)
Insecticide residue, pulp (f) toxaphene ppm	0.4	trace	trace
Insecticide residue, skin, toxaphene ppm	5-60	34	7 (e)

trace	is positive amount less than 0.08 ppm.
n/a	not applicable (no current commercial recovery)
(a)	industry 4-yr averages except Salt which is 2-yr average.
(b)	not analyzed.
(c)	sodium 2-ethylhexyl sulfate in 1975, octanoic acid in 1976.
(d)	no peeling aid used in conventional juicing/pulping.
(e)	pomace from juicing, seeds with proportionallly less skin than in peel-pulp recovery.
(f)	tolerance is 7.0 ppm in canned and fresh tomatoes.

water must be removed, either through subsequent concentration, such as for tomato sauce, or during the evaporation that occurs from holding tanks. This water can be removed after combining with other juices and pulps. There seems to be little justification for keeping recovered pulp isolated for use in a special product since economically there is an insufficient quantity of recoverable pulp to establish a separate processing line.

Tomato Washing and Sorting

The 1975 cannery peel had low mold, insect fragment, and bacterial counts that were well within regulatory tolerances. This showed that the cannery (Tillie Lewis Foods, Plant W) had an excellent washing and sorting system. In 1976, tomatoes were received before initial commercial processing; experimental sorting was varied and the results showed that hand sorting, or the equivalent, is essential to removing mold prior to peeling. Sorting was varied from zero to 20% of the peeled tomato weight; the higher sorting was necessary when the California State Grade Certificate showed 3% mold. While the Grade Certificate is an indication of mold, the tomatoes were graded about 24 hours prior so the actual mold count may be higher at the time of processing. An alternative to hand sorting is the use of high-pressure water sprays (70-120 psig) as practiced for a number of years by most canners to remove broken and moldy tomatoes.

Peel Acidification

Early and rapid acidification is necessary because the tomato is more stable at pH 4.2 than at pH 11-12; at the high pH, both color and flavor deteriorate. A rapid decrease, in less than 10 seconds, from pH 11 to 4.2 is necessary because off odor was sometimes observed when the acidification paused at pH 6-9 for several minutes. Acidification was performed either before or after the skin was separated from the pulp. Since recovery was 96% or more, there was little reason to be concerned with acid economy by acidifying after the skin removal. Therefore, the Peel Tank (Figure 1) is the preferred location for acidification because it provides a quick pH response and is an easy place to control pH.

Pulp Extraction

With the Extractor (Figure 1), the best pulp recovery and skin extraction was obtained with a 0.030-in. screen and 0.5-in. paddle-screen clearance. Larger screen sizes allowed too many skin particles and seed fragments from broken tomatoes to remain with the pulp. The 0.5-in. clearance was necessary because closer clearances, as in normal cannery practice, would grind the skin and incorporate it into the pulp. Caustic action has already loosened the tomato cells so a wider clearance is necessary. Skin and seed fragments are undesirable because they are graded as defects in products; also, the waxy skin layer carries the insecticide. Typically, the recovered pulp contained 0.4 ppm toxaphene and the skin waste had 5-60 ppm.

Peeling Aids

During the Spring 1976 laboratory peeling study, the C_6 and C_8 saturated, monocarboxylic fatty acids were the most effective peeling aids. The 150°F pretreatment was as effective, or more so, as using the peeling aid directly in the caustic applicator. For easy-peeling tomatoes, such as those suitable for steam peeling, it was possible to peel without caustic by using a 1-min. immersion in a 150°F aqueous bath containing 0.2% w/w octanoic acid. While it may be convenient to apply the peeling aid with caustic, there is no inherent reason why a peeling aid requires the same application temperature, pH, and immersion time as the caustic. Peeling aids are commonly referred to as "wetting agents" but the most effective ones may do more than reduce the interfacial tension between the tomato surface and the caustic. Some wetting agents, such as sodium oleate or sodium lauryl sulfate, will show high-wetting improvement, but they will have little effect on peeling, whether applied as a pretreatment or directly in the caustic bath. Others, such as sodium 2-ethylhexyl sulfate and sodium mono- and di-methyl naphthalene sulfonates, perform better when applied directly in the caustic bath than when used as a pretreatment. The most effective peeling aids appear to react chemically and (or) to disrupt the cell structure and allow enzyme action. This is illustrated by peeling tomatoes with only an acidic (about pH 3.6), aqueous solution of octanoic acid at 150°F. While octanoic acid performed best among the candidates, the C_4 to C_{10} saturated monocarboxylic acids showed the most promise. The time was limited and an extensive pursuit of the ideal peeling aid was not feasible. Octanoic acid occurs naturally in coconut oil, is readily available commercially in a food grade, and is priced similar to the currently used peeling aids. A food-grade peeling aid should be biologically metabolized in predictable fashion by both humans and animals or microorganisms associated with man. Octanoic acid fits these requirements.

Carboxylic Acid Peeling

The carboxylic acid peeling was done at about pH 3.6 with a 150°F aqueous solution containing 0.2% octanoic acid with a one to three minute immersion. This completely peeled the tomato varieties Tropic, Walter, Roma-VF, and VF-145-21-4 (this last one contains a uniform-ripening gene). For the VF-145-7879, 134, 198, and 13L, which are typical California processing tomatoes, the skin was loosened and peeling aided, but a subsequent caustic application was needed. With octanoic acid peeling, the peeling loss averaged about 5% as compared to 12% for caustic using commercial peeling aids. The difference was visually dramatic because caustic peel was red due to the adhering pulp, whereas the octanoic acid peel was a translucent, pale yellow because no pulp adhered.

Peeling Aid Pretreatment

Pretreatment temperature was varied from 75°F to 210°F. Initially, 150°F was chosen so as to be below enzyme-inactivation temperature. Experimentation showed that below about 140°F the peeling aid pretreatment was less effective or required long immersion, such as up to 10 minutes. Above about 170°F, even with a short dip, the tomatoes became increasingly soft and the peel loss increased. Overall, the 150°F temperature was best with the range of 140 to 160°F being practical. Even a 150°F plain (100%) water pretreatment usually showed some peeling improvement, but a peeling aid is definitely better.

Modified-Caustic Pilot Peeling

The 1976 pilot peeling at the cannery was mostly with the tomato Variety UC-134, which usually was the only tomato available and is a more difficult tomato to peel than the more prevalent VF-145-7879. When the VF-145, 198, and 13L were used, they responded similarly to that of the 134 with respect to peeling-aid pretreatment and residue in the recovered pulps.

When comparing peeling methods with a pilot line, it is possible to simulate commercial conditions but nearly impossible to duplicate scale because tomatoes change with each truck load and even within the load. Also, loading pilot equipment and duplicating caustic solutions can be quite different. For example, the usual cannery caustic applicator takes about one week to reach equilibrium between caustic and disintegrated tomato solids. However, the experimentation necessitated changing the caustic solution daily. The rubber-disc peeler is quite sensitive to the degree of loading because peel removal depends not only on the discs contacting the tomato but also on the inter-tomato rubbing and contact. The peeler was operated at about 1-t/hr so as to use nearly the same tomatoes from a three-hour period for one set of experimental-peeling variables. From a 3-hr supply period, three peeling comparisons were normally made: (1) plain caustic bath, (2) caustic bath containing peeling aid, and (3) peeling-aid pretreatment followed by a plain caustic immersion. Times, temperatures, and loading were constant during these three variations.

Effluents & Wastes

One of the prime considerations when initiating the project was not only to reduce liquid and solid effluents in terms of caustic, BOD, and COD, but to avoid creating new ones; this was successfully managed. There was no continuous liquid discharge except from washing the tomatoes, and this is present commercial practice. There was a carryover from the Pretreatment to the Caustic Applicator, and from the Applicator to the disc peel remover. These carryovers were food-grade materials, not inedible peeling aids nor effluents. Since 96% of the peel is recovered as pulp, the normal peel effluent was drastically reduced. The skin, seeds, and fibers separated by the Extractor are normal processing wastes. Since these wastes have been reacidified, they are more acceptable than with the current caustic peel for disposal on agricultural land or into a municipal waste treatment plant. The Pretreatment bath liquid was not operated for extended periods and through BOD and COD measurements were made, these likely do not represent what might be experienced under commercial conditions. Some canners currently operate their caustic applicators the full 3-mo. processing season without changing solutions, others change the caustic once a week. The pretreatment aqueous solution of octanoic acid is biodegradable whereas some of the current peeling aids are not. After peel removal, all canners rinse or flume the peeled tomatoes, and this practice would be continued with this 1976 modified-caustic peeling. Therefore, this modified caustic peeling and peel recovery would decrease current peel discharge by 96%, and the discharge would have an improved pH character.

Product Mold, Insect Fragments, & Bacterial Counts

In 1975 the peel received from the Tillie Lewis peeling operation was almost devoid of mesophilic and thermophilic bacteria. There was a slight increase during the peel-pulp recovery, but the counts were very small in comparison to those found in commercial operations at similar processing steps. Therefore, it can be assumed that the caustic-peeling operation has a strong bactericidal effect on the peel. Also in 1975, the mold and insect-fragment counts on the canned recovered pulp were uniformly low and reflect a thorough washing and sorting system at the Tillie Lewis cannery. Therefore in 1976, the experimental tomato washing was held constant, but the hand sorting was varied from zero to 20% of the peeled-tomato weight. The 1976 mold counts showed that hand sorting, or the equivalent, would be essential to maintain the mold level within tolerance. Truck loads with a California State Grade Certificate showing 1% or less mold required minimal sorting on loads above 3% mold, up to 20% of the tomato weight might need to be removed to be within tolerance on the recovered pulp. This 20% included both tomatoes showing mold and broken tomatoes which would disintegrate in the bath and not yield properly peeled whole tomatoes. Since there is normally about a 24-hr lapse between the time of picking and grading and actual processing, the mold count will increase. All this points to the necessity for an efficient sorting of tomatoes prior to peeling if the recovered peel pulp is to be usable. The results indicate that good manufacturing practices will be necessary to control the mold and insect fragments.

Product Color, Flavor, & Vitamins

Product color and flavor differed between 1975 and 1976, and this illustrates how the peeling operation affects the recovered pulp. In 1975 the Caustic Applicator liquid overflow went into the peel rather than to waste disposal; it was a local situation which could not be altered at the time, but the results show that recovered pulp could be food grade even under adverse conditions of excessive (3-fold) caustic. The color and flavor (Table 1) were degraded by caustic as were some amino acids. Amino acids were used as indicators of processing severity. The arginine:histidine ratios were 0.4 in 1975, 1.1 in 1976, and 1.3 for conventional tomato pulp. Arginine is more susceptible to caustic degradation than histidine. Flavor also suffered when the pulp was exposed to excess caustic as seen in Table I. Ascorbic acid is so easily decreased in the presence of hot caustic that it was not present in pulps from either year. Beta-carotene is quite stable, and since the outer surface of the tomato is richer than the whole tomato in this provitamin, the recovered pulp had a higher carotene value than conventional tomato pulp. In general, the 1976 recovered pulps exhibited improved color and flavor and reduced peel-aid residues compared to the 1975 pulps.

Consistency, Viscosity, and Pectin

In this pulp, there was a desirable above average number of tomato whole cells which give the pulp a heavier, thicker appearance compared to conventional tomato pulps. In general, this recovered pulp shows the consistency and texture of a good cold-break processed pulp. Serum viscosity was less than those of conventional pulps which indicates degradation of the pectin as would be expected from the caustic exposure. Evidently the consistency of this peel pulp is due to undissolved solids (cells, fibers, etc.). Insoluble solids are the primary contributors to tomato-product consistency, but pectin is important because it serves to hold the insoluble solids in suspension and reduce the tendency for syneresis. This recovered peel-pulp would be appropriate for pizza sauce or soups, which normally may use a cold-break pulp because it is desirable to thicken with starch. For other sauces or pulps where a hot-break material is normally used, combining recovered pulp with conventional pulp in a ratio of 1:3 will result in a material with the consistency and character of a hot-break pulp.

U.S. Standards of Identity

Since the proposed process modifications and materials may or may not be totally covered by the existing U.S. Food & Drug Regulations, a letter was sent to the FDA Bureau of Foods requesting their judgment on these main concerns: (1) utilization of pulp derived from caustic peeling, (2) acidification of the caustic peel with food-grade hydrochloric acid, (3) use of food-grade octanoic acid as a peeling aid with residue present in the recovered pulp, and (4) the labeling requirements when recovered pulp is utilized. Whether a commercial installation can be made under the existing regulations or whether further technical and regulatory considerations are needed will depend on the response to this letter. Pertinent regulations are 21 CFR 53.10-.40, tomato products; 21 CFR 121.1070, food-grade fatty acids; and 121.1091, chemicals used in lye peeling.

Economics

The economics for a cannery peeling operation of 40 t/hr are summarized in Table 2. Such a peeling operation might use two lye applicators, such as the FMC Hi-Ton, and either two FMC PR-20 Peel Removers or four Magnuson Model C Peel Scrubbers. The projected costs and savings are based on a 12% recoverable peel loss, 60 days operation per year, 16 hrs of peeling each day, and a $50/t pulp value. Capital and operating expenses include only those directly associated with pretreatment and pulp recovery, not the balance of the peeling process that is presumed to already exist. The capital cost could easily be greater or smaller, depending on whether existing equipment and utilities are readily adaptable or entirely new equipment would be needed. One example is that the pretreatment could be applied with an existing flume or it might require a special, positive-flow pretreatment such as that used in the pilot installation. Undoubtedly

TABLE 2. PROJECTED ECONOMICS OF A COMMERCIAL INSTALLATION

Based on: 40 t/hr tomatoes x 12% peel = 4.8 t/hr peel 96% recovery = 4.608 t/hr pulp recovered. 60 dy/yr x 16 hr/dy = 960 hr/yr		1st Year Operation $/hr	2nd Year and Thereafter $/hr
Recovered Peel-Pulp Value Based on $50/t gross value of pulp.		+ 230.40	+ 230.40
Fixed Cost, installed Capital Equipment. Depreciated in 1 yr, 960 hr.			
Pretreatment (circulation, temp. control)	- 15,000		
Chemical Supplies (tanks, pumps, piping)	- 16,000		
Extraction (pulper, piping)	- 14,000		
Acidification (pH control, agitator)	- 15,000		
General (utilities, piping, etc.)	- 35,000		
Contingency	- 20,000		
(installed total)	-115,000	- 119.79	0.00
Variable Costs			
Direct Labor (operator, cleanup, QC, supv.)	- 12.48		
Startup labor, 1st year	- 24.96		
Indirect labor (mechanic, clerk)	- 3.13	- 40.57	- 15.61
Superintendence	- 0.94	- 0.94	- 0.94
Utilities, steam, 7,230 lb/hr	- 10.84		
water, 10 gpm	- 0.07		
electricity, 78 kw	- 1.57	- 12.48	- 12.48
Chemicals, fatty acid, 1.33 lb/hr	- 1.33		
hydrochloric acid, 150 lb/hr	- 6.00	- 7.33	- 7.33
Maintenance Supplies, 5%/yr of capital	- 5.92	- 5.92	- 5.92
Miscellaneous (operating & cleanup supplies)	- 1.00	- 1.00	- 1.00
Value		+ $230.40	+ $230.40
Costs		- 188.03	- 43.28
NET RETURN ON PEEL PROCESSING		+ $ 42.37	+ $187.12
Saving on Caustic Peel Disposal ($2.50/t)		+ 12.00	+ 12.00
OVERALL RETURN ON PEEL PROCESSING		+ $ 54.37 or $52,195.20 1st year	+ $199.12 or $191,155.20 per year thereafter

different canners will use pulp values different than the $50/t which was based on the approximate value of delivered fresh tomatoes before processing.

SUMMARY

The objective of this evaluation and development was to determine the "Commercial Feasibility of Recovering Tomato Processing Residuals for Food Use". The 1975 work was an evaluation and characterization of peel from a typical commercial peeling operation. For 1976, the caustic peeling process was modified to reduce the unacceptable peeling-aid levels found during 1975. The commercial peel-pulp recovery operation envisioned would have a tomato pretreatment with a food-grade fatty acid as used in 1976 and the acidification and pulp extraction features used in 1975. The recovered 1976 pulp was Grade A, and with a capital investment which can be depreciated ciated in less than one year, the pulp recovery has a net positive value of possibly $187/hr of operation after the first year. As of now, pulp recovery from tomato peel appears to be both technically and economically feasible.

ACKNOWLEDGEMENTS

The authors appreciate the support given to this project by the tomato processing industry; not only did it ease the burden, but tasks and judgments were often shortened and made possible in a few months which otherwise might have required several years. In particular, we wish to thank Tillie Lewis Foods and Hunt-Wesson Foods at whose canneries the field work was performed. This allowed a practical approach which could not be duplicated in a laboratory or pilot plant. The U.S. Environmental Protection Agency supported in part this experimentation, and this allowed the work and development to be carried out in the short period of two years.

REFERENCES

GENERAL

1. Schultz, W. G., Graham, R. P., and Hart, M. R. Pulp recovery from tomato peel residue. Proceedings of 6th National Symposium on Food Processing Wastes, Madison, Wisconsin, April 5-11 (1975).

2. Hart, M. R., Graham, R. P., Williams, G. S., and Hanni, P. F. Lye peeling of tomatoes using rotating rubber discs. Food Technology 28:38 (1974).

3. Schultz, W. G., Graham, R. P., Rockwell, W. C., Bomben, J. L., Miers, J. C., and Wagner, J. R. Field processing of tomatoes, Part 1, process and design. J. Food Sci. 36:397 (1971).

4. Miers, J. C., Wagner, J. R., Nutting, M-D., Schultz, W. G., Becker, R., Neumann, H. J., Dietrich, W. C., and Sanshuck, D. W. Field processing of tomatoes, Part 2, quality and composition. J. Food Sci. 36:400 (1971).

5. Ostertag, R. and Robe, K. Waterless peel removal. Food Processing 36(1):60 (1975).

6. Schultz, W. G. et al. Commercial feasibility of recovering tomato processing residuals for food use. Report for 1975, Interagency Agreement EPA-IAC-D5-0795. Western Regional Research Center, ARS, USDA, 800 Buchanan St., Albany, CA 94710.

U.S. Government Code of Federal Regulations.

U. S. Government Printing Office, Washington, D.C. 20402.

21 CFR 52.5081-.5091. Canned tomato pulp grades.

21 CFR 53.10, .20, .30, .40. Standards of identity, tomato catsup, pulp, and paste, and canned tomatoes.

21 CFR 121.1070. Fatty acids.

21 CFR 121.1091. Chemicals used in washing or to assist in the lye peeling of fruits and vegetables.

Analytical Procedures

Consistency	National Canners Assoc. *Laboratory Manual for Food Canners and Processors*, Vol. 2. Avi Publ. Co., Westport, Conn. 294-6 (1968).
Natural Tomato Soluble Solids (NTSS)	*ibid*. p 560.
Mold and Insect Fragments	*ibid*. pp 300-316, 324-325.
Peeling Aid, Fatty Acids	Modification of: Macpherson, J. K. and Buckee, G. K. Estimation of free fatty acids (C to C) in wort and beer. J. Inst. Brew., *80*(6): 540 (1974).
Peeling Aids, (Na 2-ethylhexyl sulfate, sodium mono- and di-methyl naphthalene sulfonates)	Intercontinental Chemical Company. "Photometric Determination of Con-O Peel-Eze 1497." Sacramento, Calif.

Pesticide (Toxaphene)	Food and Drug Administration. *Pesticide Analytical Manual, Vol. 1*. U.S. Dept. of HEW, Washington, D.C. (1971) §212.13a(2)
Quality Factors (color, defects, flavor, odor)	U.S. Dept. of Agriculture. *United States Standards for Grades of Canned Tomato Puree (Tomato Pulp)*.
Salt (Total Chloride)	National Canners Assn. loc. cit. pp 291-292.
Total Solids (Percent Moisture)	Horowitz, William (ed.). *Official Methods of Analysis of the Association of Official Analytical Chemists*. AOAC, Washington, D.C. (11th ed., 1970) p 559.
Viscosity	*ibid*. p 369.
Vitamin A (Carotene)	*ibid*. pp 769-771.

Reference to a company and/or product named by the Department is only for purposes of information and does not imply approval or recommendation of the product to the exclusion of others which may also be suitable.

WASTE REDUCTION BY PROCESS MODIFICATION IN SWEET CORN PROCESSING

by

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INTRODUCTION

The processing of sweet corn results in the generation of large quantities of liquid and solid waste. Liquid wastes contain soluble sugars and starches and are responsible for average wastewater loadings of 27 lbs of BOD (1) per ton of corn in husk. Nearly 2.6 million lbs of sweet corn (in husk) are processed (2) hence, 70 million pounds of BOD are produced annually. Solid wastes are composed of husk, cob, and edible corn which are not removed from the cob during cutting and constitute up to 2/3 of the weight of the starting raw material.

The predominant form of preserved sweet corn is the "whole" or cut style, which constitutes 64 to 70% of all sweet corn and is produced by forcing husked ears of sweet corn against revolving or stationary sets of knives. Furthermore, most of the liquid wastes indicated above are attributed to processing this style of corn and occur during the contact of the cut-corn surface with water. Transfer of starch and sugars from the kernel to the blanch, wash, and flume fluids occurs by diffusion and by bulk mixing between the aqueous medium and the semi-solid endosperm.

The USDA Western Regional Research Center has conducted studies to ascertain whether sweet-corn kernels can be removed from the cob as intact units (unit kernels) which lack a cut surface, and whether this modification would provide sufficient waste reduction and yield improvement incentives for further development of new processing methods. Manual experiments using market corn were conducted in 1975 (3). These indicated 70% decrements for washing and blanching effluents and 20% increments for recovery of kernels on a per kernel basis.

The work described here was conducted to continue effluent and yield comparisons for intact kernels and cut kernels produced from commercial varieties of sweet corn harvested at their processing maturities, and to evaluate three experimental processing methods relative to their potential for a full-scale application.

EXPERIMENTAL METHODS

Sweet corn for these studies was grown during 1976 on irrigated land in Gilroy, CA, by the Del Monte Corporation. The varieties Golden Jubilee and Stylepak were grown as representative of commercial processing sweet corn. The glumeless variety Golden Happiness was also grown.

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When the corn attained processing maturity (monitored by moisture content of cut kernels), processing was begun (Table 1). Sweet corn was manually harvested, transported by truck to Albany, CA, composited to eliminate picker bias, divided into sublots of 35 to 70 lbs, and husked in a commercial husking machine (Food Machinery Corporation). The ears were then trimmed to exclude insect, bird, and microbial damage at the tip end. The sublots of trimmed corn were then delivered to the appropriate kernel generation stations.

TABLE 1. PROCESS SEQUENCE FOR SWEET-CORN EXPERIMENTS

Step Number	Action	Weight	Kernel Sample	Effluent Sample
1.	Harvest			
2.	Transport			
3.	Composite	X		
4.	Husk	X		
5.	Trim	X		
6.	Generate Kernels (Four methods)	X	X	X
7.	Clean (Two methods)	X	X	X
8.	Steam blanch	X	X	X
9.	Air Cool	X		
10.	Freeze	X	X	

Cut kernels were produced using a commercial rotating cutting machine (Food Machinery Corporation). The machine was set to give approximately the depth of cut obtained in commercial practice. Following production of kernels the juices adhering to the inside of the cutter were washed with a fixed volume of water and collected. This effluent was considered as part of the wash effluent since in a continuous process it would normally be included with the wash effluent.

Intact kernels were generated in three ways. The first alternative was to use the conventional cutting machine by setting the depth of cut at its maximum or deepest cut. Cutter washing was conducted as above. The second alternative was to produce kernels by the "hole-saw" technique. Here, ears were processed in a fixed diameter cutting or sawing machine sized to the ear diameter to produce a mixture including intact kernels, kernels with attached cob fragments and saw dust (3). These kernels were later screened in a batch reel separator to eliminate loose fines. The prototype hole-sawing machine was provided with a rotating sawing element into which pre-sized ears were manually fed. A third alternative was to produce intact kernels by rubbing, pressing, or plucking kernels row-by-row from longitudinal half-sections of ears produced by mechanically splitting. In the prototype for this process manually supported ear sections were placed against the surface of a continuous, moving, textured silicone rubber belt. An air stream heated to 350 to 400 F was directed against the belt surface to evaporate juices from prior contacts so as to maintain contact friction.

Normal-depth cut kernels, deeply cut kernels, hole-sawed and screened kernels, and pressed kernels were then washed in water using a pilot scale, shaker washer (A.B. McLauchlan Co., Inc.). The water used in washing was collected and its volume recorded. In some cases a brine flotation in 5% NaCl was applied to eliminate excessive cob fragments. Cleaned kernels then were blanched for 3.0 minutes on trays in a continuous steam blancher operating at 210 F. Blancher effluent was collected during and for 12 minutes after blanching, its volume measured and recorded. Finally, the blanched kernels were air cooled in forced air, and then frozen on trays in a cross-flow, air-blast freezer operating at -20 F and at 700 fpm.

Material balances and sample analyses. The mass of each sublot of corn was measured before husking and after each step indicated in Table 1. Weighed kernel samples were drawn at the points indicated in Table 1. A 70-90 gm sample was drawn for moisture analysis and a 130 to 200 gm sample was drawn for analysis of kernel characteristics. Material balances were corrected for sample weights, when appropriate. Liquid samples were drawn from the cutter wash effluent, the kernel washing effluent, and the blancher condensate. Liquid samples were analyzed for total organic carbon (TOC), chemical oxygen demand (COD), total solids (TS), soluble solids (SS), and biological oxygen demand (BOD).

Characterizations were made by visually segregating kernels into groups according to whether they were cut kernels, intact kernels, intact kernels with adhering cob tissues, or completely smashed kernels. Cob fragments and miscellaneous debris were also identified here. Each group was weighed and expressed as a percentage of the total sample weight. A classification of each group into smaller subgroups according to the depth of cut and the type of cob fragments, adhering to unit kernels will be reported later.

RESULTS

Effluent produced during the processing of sweet corn kernels from each of the four kernel generating methods are summarized in Tables 2. and 3. These data and those which follow represent 2 Stylepak, 2 Jubilee, and 1 Golden Happiness harvest. The data are shown plus or minus one standard deviation. Moreover, the basis of comparison is an equal mass of frozen product.

TABLE 2. LIQUID EFFLUENT OBSERVED DURING SWEET-CORN WASHING

Kernel Style	COD (pph)	TOC (pph)	SS (pph)	TS (pph)
Intact (Pressed)	0.62 ± 0.51	0.27 ± 0.18	0.11 ± 0.07	0.79 ± 0.46
Cut (Normal)	3.53 ± 0.91	1.33 ± 0.38	0.73 ± 0.13	2.96 ± 0.77
Cut (Deep)	2.12 ± 0.43	0.79 ± 0.17	0.36 ± 0.07	1.83 ± 0.40
Intact (Hole Saw)	0.87 ± 0.16	0.31 ± 0.06	0.17 ± 0.06	0.88 ± 0.03

Basis: 100 Mass Units of Frozen Product.

TABLE 3. LIQUID EFFLUENT OBSERVED DURING SWEET-CORN BLANCHING

Kernel Style	COD (pph)	TOC (pph)	SS (pph)	TS (pph)
Intact (Pressed)	0.059 ± 0.035	0.022 ± 0.013	0.0035 ± 0.0017	0.073±0.037
Cut (Normal)	0.148 ± 0.040	0.056 ± 0.015	0.0154 ± 0.0030	0.095±0.0726
Cut (Deep)	0.155 ± 0.040	0.060 ± 0.016	0.0137 ± 0.0059	0.173±0.0529
Intact (Hole Saw)	0.078 ± 0.041	0.029 ± 0.015	0.0043 ± 0.0012	0.099±0.040

Basis: 100 Mass Units of Frozen Corn

The characteristics of the kernels produced by each method are summarized in Table 4. This gross characterization into groups of cut kernels, intact kernels, and intact kernels with adhering cob tissue indicated the overall suitability of the material as well as the requirement for extensive cleaning or separation.

The material balances for process runs in which all four methods were examined are shown in Table 5. All of the data except those in the last line which are labeled "Frozen (gross yield)" are yields which include cob fragments as well as kernels with adhering cob tissue. The last line of entries labeled "Frozen-useable" is corrected by applying the percentage

TABLE 4. MEAN KERNEL WEIGHT PERCENT DISTRIBUTIONS FOR FRESHLY PREPARED MIXTURES

Kernel Mixture	Cut Kernels (%)	Intact Kernels (%)	Intact Kernels with Attached Cob (%)	Smashed Kernels (%)	Cob Fragments (%)
Cut (Normal)	80	12	0	3	6
Cut (Deep)	41	37	13	4	4
Intact (Hole Saw)[1]	22	52	23	1	2
Intact (Press)	0	95	3	1	1

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[1] screened

TABLE 5. MEAN EXPERIMENTAL YIELD DURING PROCESSING OF SWEET-CORN (71.8 ± 1.3% MOISTURE)

Action	Mass percent recovery			
Husked	66.1 ± 1.9			
Trimmed	64.1 ± 1.3			
	Cut (Normal)	Cut (Deep)	Intact (Hole-saw)	Intact (Press)
Prepared Kernels	38.1 ± 3.1	46.3 ± 3.0	46.4 ± 3.3	40.9 ± 2.3
Washed	36.3 ± 3.8	47.0 ± 3.5	49.9 ± 4.6	43.2 ± 2.6
Blanched	35.1 ± 3.8	44.2 ± 2.9	46.8 ± 5.3	42.8 ± 2.5
Air Cooled	33.1 ± 3.6	41.6 ± 2.9	44.0 ± 5.3	40.4 ± 2.1
Frozen (Gross Yield)	32.0 ± 3.8	39.6 ± 2.8	42.8 ± 5.2	38.8 ± 1.9
Frozen (Useable Yield)	31.0 ± 3.8	34.9 ± 4.1	34.0 ± 4.0	37.7 ± 2.4

of useable corn determined from individual classification analyses similiar to those described above. This line entry is assumed to approximate the product which would be achieved after an ideal flotation separation.

DISCUSSION

The purpose of this investigation was to assess the merits of the alternative kernel producing methods in terms of effluent generated and yield obtained. Analysis of the data presented above indicated that the most likely candidate for further development was the intact kernel produced by the pressing alternative. The factors entering this decision are described below.

Effluent data based on crude yields (i.e. yields for kernel mixtures of suitable corn with defective corn as produced in testing without a satisfactory flotation separation) indicated that the pressing process would result in the least generation of COD, TOC, SS, or TS of any of the four alternatives. Favorable reductions were also obtained for the hole-sawed intact kernels. However, the effluent from deeply cut kernels was more like that from normally cut kernels, the small difference being attributed to the inclusion of more kernel mass in the deep cut sample and to the inclusion of more intact kernels.

Organic loading in blancher effluents were much lower than in washer effluents since the blanching operation represented the second contact with water (See Introduction) and since steam blanching is inherently a low effluent method. However, the relative order of effectiveness in reducing waste was the same as observed for washing.

The reasons for the different organic loadings for each of the different kernel producing methods can be deduced from the kernel distributions shown in Table 4. Clearly, the loading is proportional to the proportion of the sample containing cut kernels. Perhaps a lower loading than was realized would have been expected from the unit-kernel, but since some kernels are broken before and during the separation by pressing, and since the kernel base is not a completely sealed unit at this stage of its maturity, this expectation was not realized.

The quality of each mixture, ie. the relative amounts of corn which must be separated and/or upgraded, can also be seen in the classification data. For instance, the pressed intact sample contains small accounts of kernels with adhering cob tissue (about 3%) whereas the cut (normal) contains about 3% of smashed kernels. In a conventional line both of these, or a portion of them would be separable by a flotation. Much larger amounts of both of these defects occur in the deep-cut and hole-sawed product making a separation and/or reclamation imperative.

The mean yield history for each style kernel is shown stepwise in Table 5; Generally, there is a loss of yield for each kernel mixture due to leaching and dehydration during the process sequence. However, this loss is greater for the cut kenels than for either of the intact kernel mixtures and reflects the greater susceptibility of the cut surface to losses.

A comparison of freshly prepared cut (normal) and intact (pressed) kernel yields shows that the intact yields were higher by a factor of 3.2% for Stylepak, 7.8% for Golden Jubilee, and 17.8% for Golden Happiness corresponding to cutting recoveries of 40.8, 37.1 and 34.4% respectively. The value of the yield increase factor depends on the value of the cutting yield, ie., the higher the cutting yield, the lower the percentage increase factor. However, large percentage increase factors do appear to be realistic since normally cutting yields fall with the range of 28 to 40% (4) depending on variety and maturity. Haber (5) reported an average recovery of 33.7% for 9 commercial varieties over an 8-year study period. Moreover, higher yield factors might have been obtained for intact kernels if all of the available kernels had been recovered. Tightly packed kernels near the butt end, ruptured kernels, and immature kernels at the tapered end were not recovered effectively.

Judging from the results shown in Table 5 it would appear that the greatest yield could be attained by either the hole-saw or the deep-cut options. However, when these yields are corrected by applying experimentally determined percentages of useable kernels, the balance shifts to favor the pressed kernels. In an attempt to take advantage of the hole-saw yield potential we proposed that the off-grade kernels of either deep-cut or hole-saw mixtures might be upgraded to suitable kernels by mechanical means. Many different approaches including abrasive milling of fresh, blanched and frozen hole-sawed kernels were applied, but were not successful since failure of the sensitive kernel pericarp usually occurred before failure at or near the kernel abscission layer. Orientation techniques were investigated which would be applied along with a cutting or pinching action to release the cob fragment. The large number of kernels and the widely different shapes and sizes which would have to be processed in this fashion precluded development along these lines.

Furthermore, when useable yield factors were applied to the effluent data of Table 2 to assess the predicted effluent in terms of useable kernels, differences obtained between the different styles are greater and the balance shifts farther in favor of the pressing option. For instance, the COD values for cut (normal), cut (deep), intact (hole-saw), and intact (pressed) kernels became respectively 3.64, 2.42, 1.10, and 0.64.

Real separations via density flotation are not as sharp as the ideal separations utilized in the arguments described above. Preliminary flotation data performed on freshly prepared and washed intact (hole-saw) kernels indicated that the percentage of off-grade kernels can be reduced to acceptable levels, but that this is achieved at the expense of loss of yield of edible kernels. For instance, to reduce the proportion of off-grade kernels produced by hole-sawing from the 20% level to the 3% level as found in freshly prepared intact (pressed) kernels would require immersion in an 11.0% NaCl solution (or its density equivalent) and would result in the loss of nearly 30% of the useable sweet corn. Because of this poor separation factor, there is additional strong incentive to utilize the preparation sequence which produces the cleanest sample to begin with, i.e., the pressing procedure.

The yield and effluent inducements for substitution of the unit or intact sweet corn kernel are augmented by consideration of the organoleptic acceptability of intact kernels. For instance, untrained panels which were served frozen and cooked samples of intact and cut kernels prepared from the same harvest, consistently expressed a preference for the intact kernel of 0.5 to 0.8 scoring units on a 1 to 9 hedonic preference ranking. This preference appears to be due to improved flavor and mouth feel of the intact kernel. Indeed, the product flavor resembles that of corn-on-the-cob.

CONCLUSIONS

Based on the experiments described above, it was concluded that:

1. Intact kernel mixtures provided for substantial effluent reductions over conventionally cut kernel mixtures.

2. Intact kernel mixtures produced by pressing provided for substantially greater yields than normally obtained during cutting.

3. The intact kernels produced by pressing provided for the highest yield with lowest effluent of the four experimental methods.

and

4. Intact kernels could have greater acceptability than cut kernels.

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REFERENCES

1. U.S. Environmental Protection Agency. Pollution Abatement in the Fruit and Vegetable Industry. Vol. 3. Wastewater Treatment in the Food Processing Industry. Office of Technology Transfer (1965).

2. Anon. The Almanac of the Canning, Freezing, Preserving Industries. Edward Judge & Sons, Westminster, MD (1973).

3. Robertson, G. H., Lazar, M. E., Galinat, W. C., Farkas, D. F., and Krochta, J. M. Unit operations for generation of intact or unit kernels of sweet-corn. Manuscript in preparation for J Fd Sci.

4. Smith, G. M. "Sweet-Corn." Chapter XI in Sprague, G. F. Corn and Corn Improvement. Academic Press, Inc. New York (1955).

5. Haber, E. S. Variations in yield and cutting percentage of sweet-corn hybids. Am Soc for Hort Sci 53 302-304 (1949).

APPLICATION OF FINE SCREENS IN THE TREATMENT OF FOOD PROCESSING WASTEWATER

by

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INTRODUCTION

Fine screens are used primarily as a pretreatment device in the treatment of food processing wastewaters. That is, they perform an operation on wastewater to make it more suitable for introduction into a more advanced treatment system. In most food processing screen applications, wastewaters are discharged to publicly owned municipal treatment systems where sewer use charges are assessed. Applications in privately owned treatment systems are usually found at larger plants or in remote locations.

The major reasons for pretreatment include protection of treatment processes to insure maximum efficiency, protection of the receiving system from damage, satisfaction of legal requirements imposed by sewer use ordinances, and reduction of treatment costs due to user surcharges.

Fine screens are presently used in numerous food processing plants to recover suspended solids from plant effluents and process streams. Fine screen devices include static screens, rotating drum screens, and vibrating screens. This paper concentrates on the diverse application and benefits of the static screen in the treatment of various food processing wastewaters. A review of applications in the vegetable and fruit processing, meat packing, poultry processing, seafood processing, dairy, and beverage industries is included. Static screen acceptance, as illustrated by this paper, is the result of proven effectiveness, simplicity, and economy.

The static screen, illustrated in Figure 1 (a), is a very simple device. The wastewater or slurry to be treated is introduced through a headbox to dampen turbulence and provide even distribution over the weir and screen. As the wastewater overflows the weir, it accelerates toward the screen. A hinged baffle reduces turbulence and optimizes flow distribution. Most of the wastewater is removed on the first slope (25° from vertical) of the three slope screen as illustrated in Figure 1 (b). Remaining wastewater is removed on the second (35°) slope and the collected solids begin to roll on the surface due to their residual kinetic energy. On the final (45°) slope, the solids drain briefly before being displaced by oncoming material. Screen openings vary from 0.010 - 0.080 inch depending on the specific application. In practice, openings of 0.020 - 0.040 inch are most common.

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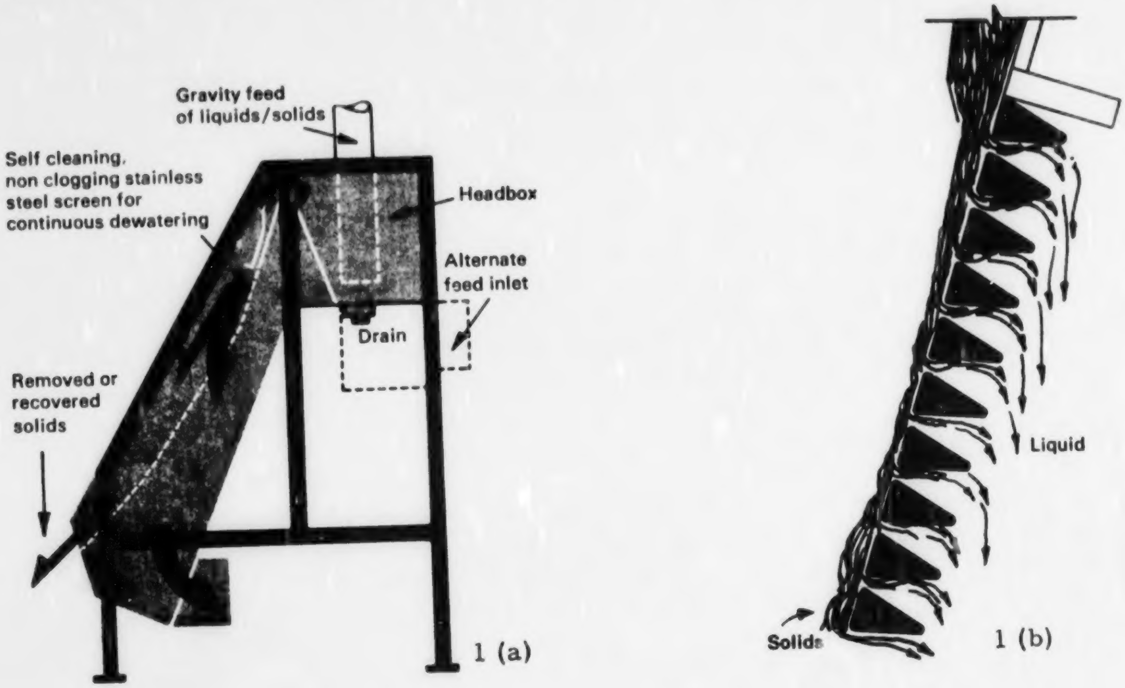
Gravity feed of liquids/solids
Self cleaning, non clogging stainless steel screen for continuous dewatering
Headbox
Alternate feed inlet
Drain
Removed or recovered solids
1 (a)
Liquid
Solids
1 (b)

Figure 1. Schematic of static screen operation.

VEGETABLE AND FRUIT PROCESSING

The vegetable and fruit processing industry uses fine screens to reduce suspended solids resulting from washing, peeling, slicing, rinsing, and packing. Essentially all processing plants, regardless of the produce handled, have two potential screening applications in common. These are wash water recycle systems and final effluent pretreatment.

The first step in vegetable and fruit processing is washing to remove dirt, stems, leaves and other residue brought in from the field. Accumulation of waste material in wash waters requires continual makeup and discharge to maintain acceptable water quality for effective washing. Fine screens are used to remove solids so wash water can be recycled. Screening and recycle results in significant savings through reductions in water consumption and wastewater treatment requirements or surcharges.

Processing plant wastewaters, containing skins, seeds, trimmings, culls, stems, leaves, and dirt, have very high BOD_5 and suspended solids concentrations. Pretreatment is usually required to minimize municipal sewer surcharges or treatment plant operating problems. Static screens have been widely accepted for pretreatment of total plant effluents. The static screen has replaced vibrating and rotating fine screens in many installations due to lower operation and maintenance requirements.

Typical performance data reported by plant personnel from various installations are presented in the following table.

TABLE 1. TYPICAL STATIC SCREEN PERFORMANCES

	Suspended Solids		BOD_5		Screen
Produce	Raw (mg/l)	%R	Raw (mg/l)	%R	Opening (inches)
Potatoes	5200	35.0	4860	9.7	0.060
Mushrooms	570	40.0	940	23.0	0.060
Tomatoes	—	84.0	—	63.0	0.020
Pickles	—	51.5	1726	39.7	0.080

Screenings recovered in vegetable processing applications are usually removed by pet food manufacturers for use in their products. Farmers also use the waste solids as a cattle feed additive or plow it into fields for the nutrient value. Solids disposal seldom incurs operating costs to the processor.

Citrus processing plants use fine screens for pulp dewatering, pectin extraction, press effluent dewatering, and flume water clarification. The recovered solids are frequently dried and used as a cattle feed additive.

Static screens have been used in wineries to remove 45 - 55% of the available juice from crushed grapes prior to the pressing operation. By removing the free juice, a press can be fed thicker grape pulp and brought to operating pressure quicker. Thus, the total capacity of the pressing operation is increased considerably.

MEAT PACKING

It is common in meat packing plants to provide separate sewers for stockpen wastes, manure wastes, grease wastes, clear waters (chilling, condensing, and cooling), and sanitary wastes. Newer plants often segregate further to permit removal of waste materials before dilution with other wastes. Much meat packing waste is originally solid (meat and fat) or sludge (manure). It is important to remove the solid material before it is subjected to turbulence which breaks it down to soluble BOD and colloidal solids that are more difficult and expensive to treat. As a result, screens have found wide use in meat packing plants for the treatment of segregated high concentration waste streams.

Screens are used to remove solids from stockpen wastes, recover paunch manure, recover hog stomach contents, remove solids from stick water, separate solids from expellar grease, dewater catch basin sludge, and recover solids from total plant wastewater.

Prior to slaughter, the animals are held in stockpens. Runways and pens are hosed down periodically producing a concentrated waste composed of manure, dirt, straw, corn, and hair. This concentrated wastewater can be effectively treated with static screens. In a typical application, a 72 inch screen with 0.040 in. screen openings would handle flows of 600 - 1100 gpm typically producing 12 tons per day of 40% dry weight solids.

Paunch manure (cattle stomach contents) and hog stomach contents contain fluids, corn, straw, and hair. This material is removed from the stomach for the recovery of tripe. The material is segregated from the total wastewater stream due to the extremely heavy loadings and operating problems it would create for a treatment facility. The wet method of paunch recovery consists of cutting the paunch open in a water flow. Static screens with 0.040 in. openings provide excellent recovery of solids from the paunch slurry. Flows of 600 gpm can be handled with a 72 inch unit producing 25% dry weight solids. Recovered solids, a usable feedstock by-product, are usually picked up by local livestock producers for use as a feed additive.

In hog processing, hogs are scalded at 150 - 190° F and dehaired in a beater-scraper type machine. Hair and scurf, a dandruff-like flake, build up in the water along with foam produced by gelatin cooked from the skins. By screening and recycling, the life of scald water can be extended reducing the total volume of wastewater and conserving heat. A typical hair recovery application would use a 72 inch screen with 0.020 in. openings to handle flows of 400 - 500 gpm.

Screens are used to remove solids from stick water in the rendering process. Stick water is a combination of product and condensation water produced in steam rendering. The stick water layer from the rendering vessel is screened prior to evaporation to produce a high protein feed additive. Solids in stick water are coarse and fibrous in inedible rendering, and soft and stringy in edible rendering. Grease normally does not accumulate on the screen because the stick water is hot (130 - 160° F) when processed.

An expellar or screw press is used to remove additional grease from rendered solids. This recovered grease contains solids which are normally removed by gravity clarification before the grease is filtered. Static screens with 0.020 in. openings have been used in this application eliminating the settling operation. Due to the fine screen openings (0.020 in.) and high grease viscosity, flow rates are low (5 - 10 gpm for an 18 inch screen). Even with the low flows, screens are an attractive alternative for this solids removal application.

Static screens have been used to dewater sludge from catch basins. Flows of 200 gpm can be handled with a 48 in. x 0.040 in. screen. Solids recovered from catch basin sludge are usually collected for landfill disposal.

Screens are used as a primary treatment device for the total wastewater from packing plants. In many cases solids collected from the total wastewater stream can be rendered. A typical application using a 72 in. x 0.040 in. screen would handle a hydraulic loading of 500 - 700 gpm. Suspended solids removals of 60% or 25,000 lbs/day of solids (40% dry weight) can be expected.

DAIRY

The modern dairy uses a considerable amount of water to wash down milking stalls, pits, lanes, and holding pens. Fine screening this highly concentrated manure laden flush water eliminates pipe plugging and secondary treatment process operating problems. Typical dairy flush water applications use a 0.040 in. screen opening to achieve 40 - 45% suspended solids and 30 - 35% COD removals. Screenings are generally 15% dry weight solids with 95% volatile material.

POULTRY GROWING AND PROCESSING

Wastewater from poultry growing farms is composed of manure, feathers, grain, wood chips, and grit from washing the growing barns. Screens are effective for the treatment of these solids laden wastewaters to remove approximately 50% of the suspended solids prior to biological treatment processes.

Poultry processing plants generally segregate wastewaters into offal and feather streams. The offal wastewater normally passes through an offal separator (coarse drum screen) to remove large renderable material. The feather laden wastewater passes through a drum or stationary screen where the feathers, a saleable by-product, are removed. Following these coarse process screening operations, the two waste streams which still contain significant quantities of small suspended matter are combined into a total plant effluent. The Hydrasieve is generally used on the total effluent to remove additional renderable solids and reduce the load on the plant's secondary treatment system.

Poultry processing plant applications normally use a 72 in. screen with 0.020 in. openings to handle up to 500 gpm. Suspended solids removals of 50% are typical.

Texas A & M University recently conducted evaluation tests using a static screen to pretreat chill tank effluents. Test results on this low flow, high load application indicated 40 - 50% suspended solids and 30% BOD_5 reductions.

SEAFOOD PROCESSING

Various seafoods, even though physically quite different, are processed through a series of similar steps. Fresh catch arriving at the processing plant is sometimes prewashed to remove loose dirt, silt, scales, and other debris. The seafood is then conveyed through peelers, scalers, or shellers to remove protective coverings. The roughly cleaned seafood then passes through a series of washing operations where waste materials are removed from the meat. Inspectors then remove culls and remaining bits of waste solids prior to packaging. Wastewaters from the various processes flow to a collection sump from which they are pumped to a static screen with 0.020 - 0.030 in. openings. The screen effectively removes heavy solids (scales, shells, feelers, viscera, culls, etc.) which produce high sewer surcharges if discharged to municipal systems or sea gull problems if ocean discharged.

Due to the high protein and nutrient content of waste seafood solids, they are usually sold to pet food manufacturers who pick up the waste solids at the processing plant. Hydrasieves have been used as described in all types of shell and finfish processing plants.

BREWERY, DISTILLERY, AND WINERY

Screens are used in the brewing industry to recover spent grains, dewater spent hops, and remove labels, glass, caps, cork, etc. from caustic bottle washing solutions.

Wineries use screens to remove stems from de-steamming operations and free juice from crushed grapes prior to pressing.

SUMMARY

Static screen application guidelines are summarized onthe following page. As illustrated here, the fine static screen has gained wide acceptance for solids removal in the food processing industry due to its effectiveness, simplicity, and economy. It has replaced other fine screening devices in numerous applications where minimum maintenance is required. Extremely rapid return on investment has been experienced by many food processing users through reduced sewer surcharges or by-product recovery.

TABLE 2. STATIC SCREEN APPLICATION GUIDELINES

Industry/Application	Screen Opening (in.)	Susp. Solids Removal (%)	% Dry Wt. Solids	Flow Rate (72" Unit) (gpm)
Vegetable and Fruit Processing	0.020-0.080	35 - 85	10 - 15	400 - 1000
Meat Packing				
. Pen Washing	0.040	30 - 35	40	600 - 1100
. Paunch Manure Recovery	0.040	30 - 35	25	600
. Scald Tank Recycle	0.020	30 - 35	25	400 - 500
. Stick Water	0.020	30 - 35	5 - 10	300 - 400
. Expellar Grease	0.020	30 - 35	10	20 - 40
. Catch Basin Sludge	0.040	30 - 35	20	300
. Total Plant Wastewater	0.040	30 - 35	40	500 - 700
Dairy	0.040	40 - 45	15	450
Poultry				
. Growing Facilities	0.040	50	15	400 - 500
. Processing Plant	0.020	50	15	400 - 500
Seafood Processing	0.020-0.030	30 - 50	10 - 15	600
Brewery				
. Grain-Hops Recovery	0.030	50	20	500
. Caustic Wash Water Recycle	0.040	75 - 80	5	300
Winery				
. Juice Removal	0.020	25	8	400

PRELIMINARY EVALUATION OF ANAEROBIC SLUDGE DIGESTION FOR THE TUNA PROCESSING INDUSTRY

by

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INTRODUCTION

The tuna processing industry of southern California is somewhat unique among the segments of the seafood industry in that considerable quantities of biodegradable waste are routinely available to support biological treatment processes. The plants are congregated and produce similar waste products for disposal. Although one plant may close down for periods ranging from days to several weeks, other nearby plants typically continue to produce considerable amounts of waste solids.

Due to the high organic solids and lipid content of the processing wastes escaping screening, the most suitable means of waste component capture is dissolved air flotation (DAF). The flotation process is assisted by chemical addition (i.e., lime, alum, polyelectrolytes, ferric chloride, sodium aluminate) to promote particle contact and coagulation. The coagulated organics are buoyed to the surface by the dissolved air and removed by surface skimming paddles. The skimmed waste is called sludge.

Disposal of sludge has created operational and economic difficulties for the tuna industry. Presently, the high water content tuna sludge is trucked to land disposal at the rate of 9,000 GPD by one major processor located at Terminal Island, California (1). Although land disposal of unstabilized sludge is presently practiced, restrictions concerning the disposal of such material is envisioned. The cessation of land disposal would require barging or incineration operations, both of which may be prohibitively expensive.

Sludge digestion is a common practice in municipal wastewater treatment systems, with anaerobic digestion being the predominant process. Anaerobic digestion reduces the sludge volume, improves dewaterability, and provides a useful energy supplement in the generated methane gas. The process is commonly termed as a two-stage biological process. In the first stage, the complex organics of the wastes are converted to volatile acids. The second stage involves the conversion of this volatile acid substrate to methane and carbon dioxide gas. The bacteria responsible for the stages of treatment are two distinct groups which must be in balance for the process to proceed.

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Anaerobic digestion has been considered as a sludge treatment application for the tuna industry, but past in-plant practices have negated serious consideration (2). Saltwater is used to partially thaw the catch aboard the vessel and is transferred into the plant waste sump during unloading. The catch is further thawed, prior to processing, in brine tanks located inside the processing facility. The saltwater used in these operations becomes highly polluted and requires treatment by the processor prior to discharge. This saltwater intrusion into an otherwise fresh water process creates periods of high salt content in the generated sludge that could cause toxicity in anaerobic organisms (2, 3). The net result on an anaerobic sludge treatment process would be either organism acclimation to the salt concentration with a reduced treatment efficiency or digester failure in the case of slug loads on a digester. Proposed alternatives are:

(1) Provide fresh water thawing, with recycle capability, inside the plant. This is presently practiced in many plants for reasons exclusive of sludge salt concentration.

(2) Return holding water to the vessel upon completion of catch offloading. The polluted water could then be pumped overboard at sea. With the institution of fresh water thawing inside the plant, the salt discharged from vessel holds may not be a significant source.

If such alternatives were instituted, more reliable wastewater treatment would result, and the tuna sludge disposal costs may be reduced by incorporation of the anaerobic digestion. Anchovie and mackeral sludge from other lines would have to be segregated and disposed of without digestion due to an unavoidable salt influx during processing.

In light of the potential for in-plant changes and the persistent sludge disposal problems, an anaerobic digestion demonstration project was undertaken by the Utilization Research Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service (NMFS), Seattle, Washington.

TABLE 1. TEST SLUDGE ANALYSIS*

	Average	SD	n	Units
pH	6.4	--	--	--
Alkalinity	962	27.5	3	mg/l as $CaCO_3$ to pH=4.6
Ammonia NItro.	30.8	2.3	6	mg/l
Protein	1.9	.2	6	% of Sludge
Lipids	3.5	.7	8	% of Sludge
Total Solids	8.2	.5	8	% of Sludge
Vol. Solids	83	1.9	8	% of TS
Total COD	139.4	3.3	4	gm/l COD
Soluble COD	9.6	0.4	5	gm/l COD
Spec. Grav.	1.02	--	--	--
NaCl	0.07	.01	5	% of Sludge

*Digester feed diluted 1:1 with distilled water

Test sludge was obtained from a pilot DAF unit operated by NMFS at Whitney-Fidalgo Seafoods, Anacortes, Washington. The sludge was essentially salt-free, as the tuna were offloaded partially frozen and air thawed at the processing plant. Wastewater treatment consisted of screening, followed by DAF using 200 ppm alum, 100 ppm lime, and 5 ppm anionic polymer. The test sludge should adequately represent a sludge which would result from the previously discussed in-plant changes at the major tuna processors. The test sludge analysis is presented in Table 1.

Toxicity

Toxicity of any substance must be discussed in terms of concentration. The effect of any substance on the metabolic rate of an organism is a function of the substance concentration. As evidenced in Figure 1, the increase of a substance concentration produces organism growth which may be described as stimulatory, constant, and finally, toxic.

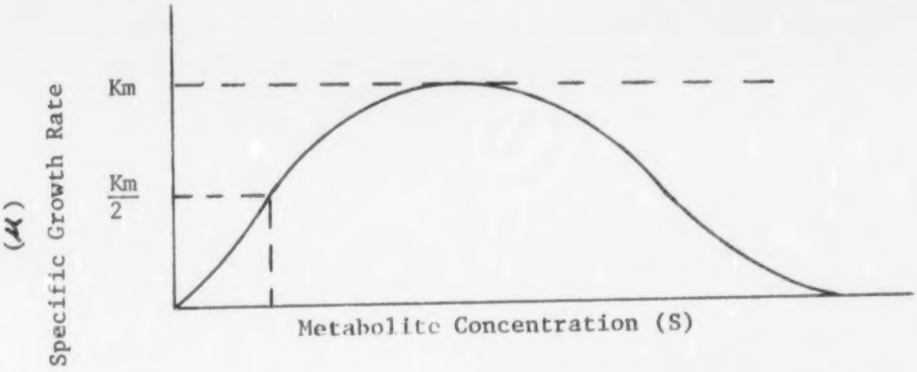

Figure 1. Effect of metabolite concentration on growth rate (4).

Other factors which enter into a discussion of toxicity are antagonism, synergism, and acclimation. Antagonism is the reduction in apparent toxicity of a substance by the presence of another. Synergism is the increase in the apparent toxicity of a substance by the presence of another. Acclimation is an adjustment of the organisms to the adverse effects of a toxic substance concentration. All three of the phenomena are concentration dependent, with acclimation being additionally dependent upon the rate of increase in the toxic substance concentration.

Five light metal cations have been investigated (5) with relation to their effect on acetate-utilizing methane bacteria. The cations were studied singly and in combination to validate the antagonistic and synergistic relationships. The results are of little help to a design engineer due to the specific nature of the organic loading, only one solids retention time, and the definition of toxicity being related to a control reactor. However, it is possible to categorize the cations for a slug feed system in order of increasing apparent toxicity on a molar basis as sodium (Na+), ammonium

(NH4+), potassium (K+), calcium (Ca++), and magnesium (Mg++). In addition, the antagonist for the primary cation present in sea water (Na+) was identified as being potassium. The concentration of antagonist required to counteract a toxin was very small, as evidenced in Table 2.

TABLE 2. EFFECT OF POTASSIUM ANTAGONIST ON SODIUM TOXIN

Toxin Concentration	No Antagonist Reaction Rate % Control	Range of Peak Antagonist Concentration M	Peak Antagonism Reaction Rate % Control
.3	54	0.002 - 0.06	72
.4	30	0.005 - 0.03	56

Because of the limitations of a control reaction comparison, the effects of potassium and sodium combinations were studied at various solids retention times (6). By incorporation of various solids retention times, it is possible to study the kinetic effects of toxicity and antagonism.

The effect of sodium on the organisms was manifest as a lowering of the cell yield constant and an increase in the organism decay rate for increases in sodium concentration. This is significant, because the ability of the organisms to process substrate was not affected while the organism population was lower than would normally occur. With the addition of 0.03 M potassium to a process retarded by 0.35 M sodium, the yield and decay rates returned to near normal values. Therefore, achieved was a confirmation of the antagonistic ability of potassium to sodium toxicity.

The significance of the kinetic approach to toxicity is that process design variations dependent upon irregular cation concentrations can be systematically approached. After obtaining the ionic character of a waste to be treated anaerobically, the designer can more accurately predict effluent quality and antagonist concentration required to achieve adequate treatment. This is accomplished by adjusting the kinetic constants for the ionic concentrations present in the waste.

For this study, insufficient data concerning the ionic character and kinetics of tuna sludge digestion are available. This limits speculation as to the ultimate value of the kinetic constants for high-salinity tuna sludge digestion. The effect of high-salinity sanitary waste discharges from vessles to municipal biological treatment systems has been appraised for possible antagonistic combinations of cations in sea water (7). It was theorized that sufficient antagonist cations are present in sea water to sustain the anaerobic process in a digester at 12,000 ppm NaCl. Other investigators (8) surveyed municipal treatment systems in Florida which operate anaerobic digesters with constant NaCl inputs of 7,000 to 10,000 ppm. The units operate satisfactorily, but continuous levels above 13,000 ppm were considered to be excessive for stable operation.

Star-Kist Foods (1), located at Terminal Island, California, reports NaCl concentrations ranging from 6,000 to 14,600 ppm in the final sludge from their DAF unit, with average NaCl concentrations being about 13,000 ppm. Although the possible accumulated NaCl concentration in a digester cannot be estimated, it is reasonable to expect a toxic condition due to variations in salt loading and a high average salt concentration.

The tuna sludge used in this study was obtained from a brine-free process and had a measured NaCl of 700 ppm. This sludge should adequately represent a sludge which would result from the in-plant thawing operation changes previously discussed.

Test Procedure

The study was conducted using three 2,000 ml flasks suspended from a wrist action shaker into a controlled temperature (97°F) water bath. Generated gas was collected over an acid/brine solution contained in calibrated 4,000 ml flasks.

Precautions were taken to assure a fresh test sludge by refrigerating the sludge following collection. The sludge was transported to the laboratory and divided into 400 ml packets prior to freezing at 0°F. Sludge packets were thawed as required and refrigerated when not in use.

The digesters were seeded with 750 ml of digesting sludge obtained from a municipal digester. Sludge feeding was commenced on the following day at solids concentration less than 1%, with a gradual increase to the test solids concentration of 4.1% (raw sludge concentration = 8.2% solids). The raw sludge was diluted 1:1 with distilled water and warmed to 97°F prior to feeding. The units were fed once per day using volumes consistent with the desired digester detention time. Air contamination was avoided by using a 50 ml plastic syringe for all feeding operations. However, the feed sludge may have been oxygen saturated due to vigorous mixing during syringe filling operations.

Three digesters were successfully operated at detention times of 8, 12, and 15 days. Prior to data collection, all digesters were operated a minimum of 3 detention periods to assure greater than 95% seed sludge removal.

Laboratory Analysis

All analyses were conducted in accordance with Standard Methods (9) with the following exceptions:

> Raw sludge volatile solids analysis conducted as prescribed by A.O.A.C. (10). The method involved pre-drying of the sample using heat lamps prior to ashing in the muffle furnace. This was required to avoid flare-up in the muffle furnace due to the high lipid content.
>
> Protein analysis was conducted on a Kjeldahl apparatus using a wet sample. Ammonia nitrogen content was subtracted from the TKN prior to protein concentration calculation.
>
> Total alkalinity of the sludge was determined by titration with 0.02N H_2SO_4 to pH = 4.6 using electrode pH probe and magnetic stirrer.
>
> Gas samples were collected over acid/brine solution in glass transfer bottles. Analysis for CO_2 was by Orsat; analysis for CH_4 by gas chromatograph. Methane percentage was a calculated average using peak height on a strip chart recorder. The instrument was calibrated prior to each day's use.
>
> NaCl by Quantab #1176 chloride titrator after glass fiber paper filtration.

Results

The results are presented in Tables 3 and 4, listing observed removal and operating parameter values for each digester. Of particular significance is

TABLE 3. SPECIFIC REMOVALS

	Digester Detention-Days		
	8	12	15
Total Solids	41%	54%	47%
Volatile Solids	49	65	57
Total COD	47	59	64-70*
Protein	26	47	47
Lipids	77	77	83

*COD-methane balance indicates the raw sludge packet fed to the 15-day digester was of considerably higher COD concentration, 85 gm/l versus 69.7 gm/l average.

TABLE 4. DIGESTER OPERATING PARAMETERS

	$\overline{8}$	SD	n	$\overline{12}$	SD	n	$\overline{15}$	SD	n	UNITS
pH	6.8			6.8			6.9			
Total Alk.	2909	58	5	3450	202	6	3580	141	8	mg/l as $CaCO_3$
Total Solids	2.3	0.3	11	2.1	0.2	8	2.3	0.2	10	%
Vol. Solids	70.6	6.3	11	63.1	5.1	9	67.9	11.7	9	% of TS
Total COD	36.9	4.3	6	28.8	1.5	6	25.0	2.1	6	gm/l
Soluble COD	6.9	0.9	3	7.2	1.2	3	6.9	0.2	3	gm/l COD
Protein	0.7	0.1	3	0.5	0.1	3	0.5	0.1	3	% of sludge
Lipids	0.4	0.1	4	0.4	.1	4	0.3	0.2	9	% of sludge
Vol. Acids	431	47	3	400	40	4	355	21	5	mg/l as acetic
Ammonia-Nitro.	1000	90	3	890	42	3	1095	19	4	mg/l
Gas Prod.	1279	90	8	1287	67	15	1306	39	13	ml/day @ STP
Gas - % CH_4	70	3.1	5	76	2.3	5	80	1.8	4	%
Gas - % CO_2	26	1.4	5	23	1.2	5	22	0.4	4	%
VS Loading	0.27			0.18			0.14			#vs/FT$^{\underline{3}}$ day
CH_4/VS	4.5			7.3			9.9			$\frac{FT^3 CH_4}{\#VS\ added}$

the high methane content of the generated gases, which exceed the accepted average production (67% CH_4) achieved by municipal digesters. Rudolfs (11) identified a high correlation between grease content and combustible gas production.

As may be observed, the percentage removals for the 15-day digester are somewhat lower than one would expect. This may be explained by the fact that the 15-day digester data were collected after completion of the 8- and 12-day units. Although every effort was made to assure uniform distribution of the test sludge during initial 400 ml packet proportioning, the sludge packet fed to the 15-day digester evidently was of a different content than previous packets. The analysis of the feed sludge was conducted using samples from different freezer packets, but the feed sludge was not continually tested throughout the experiment. Although the removal percentage relationships between the digesters are not consistent, the purposes of this experiment have been achieved through successful digester operation.

Daily methane production, effluent COD, and the stoichiometric ratio of 350 ml methane per gram COD stabilized may be utilized to estimate the influent COD concentration for a digester. The 8- and 12-day digesters balance within 8% of the analytically determined influent concentration of 69.7 gm/l COD. The 15-day digester, however, requires an assumed influent COD of 85 gm/l in order to balance. This value has been applied to Table 3 as indicated.

The non-degradable COD of the feed sludge was approximately 24 gm/l. This assumes that the degradable COD remaining at higher retention times was comparable to the COD levels experienced by O'Rourke (12). The work by O'Rourke demonstrated that the effluent degradable COD from a digester is predictable and independent of the influent strength. Therefore, for a complex waste, the COD percentage removal by a digester depends on the temperature and solids retention time.

The settling properties of the sludge were greatly improved as a result of digestion. Although fines are evident in the supernatant during a short settling period, laboratory centrifugation of the digester effluent produced a visually clear effluent. This improved dewaterability is considered to be a result of releasing bound water from the organic solids and the high removal of lipids from the sludge. However, it should be pointed out that the sludge was frozen prior to digestion. Resuspension of the raw sludge after thawing produced a sludge with poor settling properties. Centrifugation of the raw sludge produced a multi-layered sample with considerable solid retention in the lipid layer.

APPLICATION EXAMPLE

The costs for certain facets of discharge control may be minimized through application of recognized techniques. It is the purpose of this paper to discuss anaerobic sludge digestion in terms of sludge volume reduction, combustible gas generation rates, and sludge disposal frequency.

The industry is encouraged to conduct an investigation on a scale far greater than undertaken by this study. The construction and operation of a pilot scale system is advisable for two reasons:

(1) Obtain specific design data;

(2) Train and familiarize personnel with the process. This may prove to be as important as the collection of the pilot plant operating data.

The application example presented in this section is sized for one plant using conservative design values. In actuality, the most economical method of sludge disposal would be a communally operated sludge processing facility. The processors are located virtually next door to one another and have common sludge disposal costs, which identifies cooperation as a major factor in reducing overall sludge disposal costs.

Based on the results of this study, and Metcalf and Eddy (13), it is reasonable to assume for a single complete mix heated digester:

8 FT^3 CH_4 per lb. VS added
55% total solids reduction
9000 GPD raw sludge (1)
Other sludge characteristics the same as the test sludge.

Tank capacity to meet the requirements of an actual installation should be determined from pilot plant data and, hopefully, the application of a mathematical model. The digestion of industrial waste is a very specific process and digester loading parameters may vary from successful municipal loadings. In the interest of conservatism, a high sludge detention time will be used to size the digester.

Metcalf and Eddy, Inc. (13) report that loading rates of 0.10 to 0.40 lb of volatile solids per cubic foot per day and hydraulic detention periods of 10 to 20 days are practicable for high-rate digesters. The main purpose of digestion of the tuna sludge is improved dewaterability and volume reduction. In order to achieve these goals with a minimum of operational difficulty, a 30-day detention period with a loading of 0.14 lb of volatile solids per cubic foot per day will be proposed. This loading is conservative and well within the above suggested loading range. A schematic of the example system is presented in Figure 1. The Port of Los Angeles reports that non-waterfront sites, near the processors, could be leased. The land lease cost is based on a 100 x 100 parcel and is listed in Table 5.

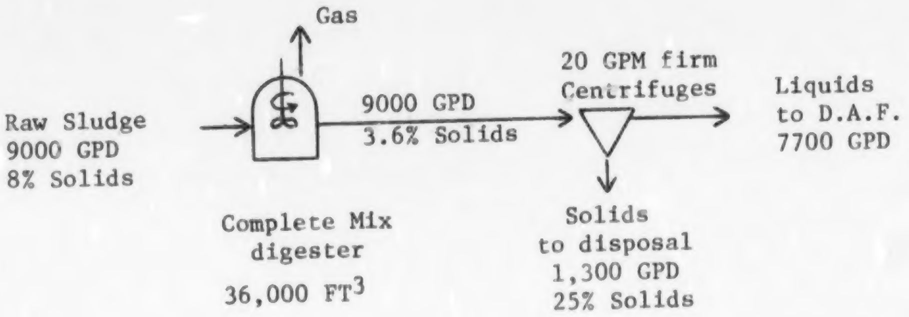

Figure 1. Schematic diagram of example installation

The digested sludge observed during the course of this study exhibited good settleability and, therefore, should centrifuge to approximately 25% solids after digestion (14).

Projected Performance

A total dry solids loading of 6,100 pounds per day is calculated (sp. grav.= 1.02). After digestion with a 55% total solids reduction, the total dry solids remaining is 2,750 pounds per day.

If we assume that this effluent (containing 2,750 pounds dry solids) is centrifuged to 25% solids concentration and a specific gravity of 1.04 is attained, the reduction in disposal volume and weight may be calculated. These calculations result in approximately 86% reduction for both disposal weight and volume.

The combustible gas production achievable from such a system is insignificant in comparison to the natural gas volumes used by a processor for cooking, canning, and can fabrication operations. However, the generated gas would be too valuable to flare off and must be considered as a marketable item. Assuming the gas is 78% methane and has a net heating value of 700 BTU per cubic foot of digester gas, the equivalent value in terms of natural gas ($0.14/therm) may be calculated. After consideration of the digester heating requirements (15), the residual gas value of $15,500 per year is obtained.

Present Value Comparison

In the following section, the example system will be cost estimated and subjected to a present value analysis versus the present disposal costs. An important feature of this comparison is that the present disposal method is severely affected by fuel inflation, since the costs incurred are primarily for trucking. Inflation for trucking costs can be expected to exceed the national overall inflation rate.

The comparison was conducted for various before-tax cost of capital, national inflation, and fuel inflation rates. An 7% investment tax credit was applied against the construction costs and the capital equipment was depreciated using the straight line method over 20 years. The tax savings due to depreciation (50% allowed) was applied against the yearly operation and maintenance cost. The equivalent value of the excess sludge gas in terms of natural gas was computed by converting from BTU to therms and multiplying by the local billing factor. This equivalent value is considered to be a positive cash flow value, since plant energy requirements can be supplemented. Financing costs are not included in the cash flow because they are inherent in the present value calculation.

The cash flow result of this analysis is presented in Table 5, which shows a total annual reduction in expenditures of approximately $78,000. Information on present annual tuna sludge disposal costs was provided by Star-Kist Foods (1).

TABLE 5. DISPOSAL OPTION COST SUMMARY
SEPTEMBER, 1976 DOLLARS

PRESENT			EXAMPLE	
	Total Construction			$500,000
$ 5,000	Yearly O&M		$41,000	
100,000	Yearly Disposal		12,000	
	Yearly Land Lease (Port of Los Angeles)		2,300	
	Yearly Gas Savings	(-)	15,500	
	Yearly Depreciation Tax Savings	(-)	12,375	
$105,000	COST PER ANNUM		$27,425	
	TOTAL CONSTRUCTION COST			$500,000

It should be pointed out that the construction, maintenance, and operation costs were developed from graphs published by the Environmental Protection Agency (EPA) (16). The EPA graphs were produced for use in cost estimating municipal plants, not small industrial applications. A complete engineering cost study for a proposed installation may provide more accurate and current cost figures on which to base management decisions. The costs obtained from the EPA were updated to 1976 costs by data provided in the Engineering News-Record (17).

Equations and values used in the present value comparison are:

Present Method

$$PV_1 = \sum_{t=1}^{20} \left[A \left[\frac{1+i_f}{1+c/c}\right]^t + B \left[\frac{1+i_L}{1+c/c}\right]^t \right]$$

where

PV_1 = present value of disposal cost and O/M cost over 20 years
A = yearly disposal cost; \$100,000
B = yearly O/M cost; \$5,000
i_f = assumed fuel inflation rate; 5 to 25% by 5% increments
i_L = assumed national inflation rate; 4 to 20% by 2% increments
c/c = assumed before-tax cost of capital 2 to 50% by 2% increments
t = terms; 20 years

Example System

$$PV_2 = M + \sum_{t=1}^{20} \left[(N-T) \left[\frac{1+i_L}{1+c/c}\right]^t + (P-Q) \left[\frac{1+i_f}{1+c/c}\right]^t \right]$$

where

PV_2 = present value of construction, disposal, tax savings, excess gas, and O/M costs.
M = construction cost; \$500,000
N = yearly O/M and land lease costs; \$43,300
P = yearly disposal cost; \$12,000
Q = yearly excess gas value; \$15,500
T = yearly depreciation tax savings; \$12,375
i_f, i_L, c/c, t as before

These equations and values were run on a computer with the printout showing PV_2-PV_1 as a function of progressing rates of national inflation, fuel inflation, and before-tax cost of capital. The cross-over point, where PV_2-PV_1 equals zero, occurs approximately at capital rates of 20, 27, 34, and 40% for fuel inflation rates of 5 to 20% by 5% increments, respectively. These cross-over points hold for all values of national inflation analyzed, which implies that fuel cost and initial construction cost are the prime values.

Similarly, the point at which the 20-year savings equals the initial construction cost (\$500,000) can be determined. This point occurs at capital rates of 9, 15, 21, and 27% corresponding to the 5 to 20% rates of fuel inflation analyzed.

A firm would have to achieve a before-tax return on an investment in excess of the above capital rates in order to justify alternative uses for the money. If the analysis parameters are excluded and consideration is given only to the total construction cost and annual cost savings presented in Table 5, the minimum internal rate of return on the investment is 14.5% for a term of 20 years.

CONCLUSIONS

Admittedly, the installation and operation of a digestion system is a major undertaking. However, unlike other treatment systems, anaerobic digestion offers long-term operational savings. This savings would be realized primarily because of energy unavailability and energy-dependent industries (trucking) cost increases. This will be particularly true, according to Business Week (18), in southern California during the next five years. In California, natural gas is the source of 55% of energy. Curtailments of natural gas supply to industry results in shifts to alternative energy sources (petroleum-based) and overtaxing of the alternative supply.

The resulting shift from natural gas to alternative fuels will certainly strain the production/distribution capacity and the consumer's pocketbook. Therefore, sludge disposal costs may rise disproportionately to normal inflationary costs. This would tend to highlight the savings in disposal volume due to solids reduction and improved dewaterability possible through anaerobic digestion.

Such trends would only serve to accelerate the cost justification for installation of anaerobic digestion facilities in the tuna processing industry. Due to the close proximity of the plants, a commumal effort would serve to reduce the operating costs per plant.

REFERENCES

1. Evich, V.J., Engineering Manager, Star-Kist Tuna, T.I., CA. Personal communication, 1976.

2. Development Document; Catfish, Crab, Shrimp, and Tuna; Point Source Category EPA-440/1-74-020-a (1974).

3. Chun, M.J., et al., "A Characterization of Tuna Packing Waste." Water and Sewage Works, 117:10, 3-10, 1970.

4. Kugelman, Chin, "Toxicity, Synergism, and Antagonism in Anaerobic Waste Treatment Processes," Advances in Chemistry Series 105, 1971.

5. Kugelman, I.J., McCarty, P.L., "Cation Toxicity and Stimulation in Anaerobic Waste Treatment. I. Slug Feed Studies." J. Water Pollut. Contr. Fed. (1965) 37, 97 and "...II. Daily Feed Studies," Proc. Ind. Waste Conf., 19th, Purdue University, 1965.

6. Chin, Kugelman, Molof, "The Effect of Monovalent Cations on the Methane Phase in Continuous Digestion Systems," as cited by reference (4).

7. Lellelid, "Appraisal of Watercraft Waste Impacts on Municipal Wastewater Systems, " Masters thesis, University of Washington, 1977.

8. Reynolds, Smith, Hills, "Engineering Report on Shore Disposal of Ship Generated Sewage at Activities in the Eastern Area," Naval Facilities Engineering Command, NTIS: AD 747 998, June, 1969.

9. Standard Methods for Examination of Water and Wastewater, American Public Health Association, Wash. D.C. (1975).

10. Assn. of Official Analytical Chemists, Washington, D.C. (1973).

11. Rudolfs, W., "Decomposition of Grease During Digestion, Its Effects on Gas Production and Fuel Value of Sludges," Sewage Works J. (1944).

12. O'Rourke, J.T., "Kinetics of Anaerobic Treatment at Reduced Temperatures," Doctorial thesis, Stanford University, 1968.

13. Metcalf and Eddy, "Waste Water Engineering Collection, Treatment, Disposal," McGraw-Hill Company, 1972.

14. E.P.A., "Processing Design Manual for Sludge Treatment and Disposal," E.P.A. 625/1-74-006 (1974).

15. Water Pollut. Contr. Fed. Manual of Practices No. 8 (1972).

16. E.P.A., "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities," E.P.A. 17090 DAN (1971).

17. Engineering News-Record, "Costs Scoreboard," Vol. 197, No. 9; Vol. 187, No. 1.

18. Business Week, "The Natural Gas Shortage Gets Worse. . .," No. 2451, 9-27-76.

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REUSE OF BRINES IN COMMERCIAL CUCUMBER FERMENTATIONS

by

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INTRODUCTION

Spent brine remaining after cucumber fermentations is a difficult waste disposal problem. Usual fermentation practice will result in production of about 40% by volume spent brine in a fermentation tank. As a rule this brine will contain 9-15% NaCl, the BOD will be 10,000-15,000 ppm and the pH will be 3.2-3.5. These characteristics make biological treatment of the waste relatively difficult. In locations with limits on total dissolved solids it may be impossible to discharge the salt produced by normal tankyard operations.

Recent efforts have been directed toward development of recycling procedures for brines as a means of minimizing the waste generated by a tankyard. The current project was designed to evaluate commercial application of pasteurization and chemical treatments for spent brine.

Potential for Waste Reduction by Recycling Brine

Figure 1 shows theoretical calculations of the pounds of NaCl which will be discharged per bushel (50 lb) of cucumbers in a normal fermentation. Curve "a" shows the salt losses without brine recycling as a function of the salt concentration in the fermentation tank. Curve "b" is the salt loss from cucumbers which are desalted in fresh water to bring the salt concentration down to acceptable levels. This loss will occur whether or not recycling is practiced. The difference between curves "a" and "b" at any given salt concentration is the potential saving of salt which can be realized as a result of recycling.

It must be recognized that salt losses beyond the theoretical loss will occur in most tankyards. First, the tank facilities are usually of wood construction. A significant fraction of these tanks will leak. The amount of leakage can vary from slight to very substantial depending upon the state of repair. Secondly, the tank is normally open in order to utilize sunlight to inhibit yeast and mold growth on the surface of tanks. During periods of rain the tank will overflow with the loss of some brine. The salt loss from tanks was calculated by subtracting the amount of salt in a tank based upon salt concentration and the volume of brine and cucumbers in the tank from the total amount of salt added as recycled brine, dry salt and make up brine. This evaluation of salt balance showed a loss of about 1 lb of salt per bushel of cucumbers brined.

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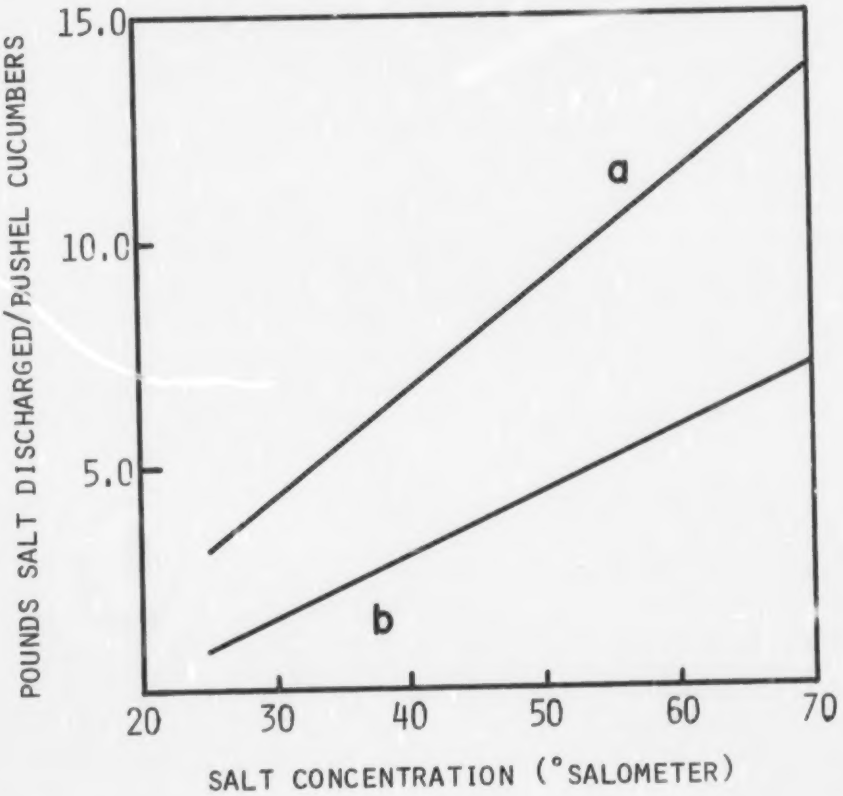

Figure 1. Theoretical salt discharge from cucumber fermentations. Calculations based upon a 65:35 fresh cucumber:brine ratio. Curve a--salt discharge without recycling. Curve b--salt discharge with brine recycling.

Geisman and Henne (1,2) developed a chemical procedure for brine treatment. Brine pH was raised above pH 10 and held for 24-48 hr. A sludge layer was removed and the pH of the brine was adjusted to near 7 with HCl. After treatment, the brine could be reused as a cover brine in subsequent fermentations with no apparent adverse effects on the fermented cucumbers. Further investigations of this recycling technique (3) confirmed these results, but also indicated that pasteurization of the brine followed by a pH adjusted to 4.5-5.0 would serve as an alternative treatment method.

The objectives of this project were to compare the chemical and pasteurization procedures in commercial brining operations and to evaluate the adequacy of the treatment procedures.

Brine Treatment Procedures

The primary purpose of brine treatment is to assure the processor that recycled brine, which is normally held for a period of months in open brining tanks, will be free of pectinase enzyme activity which could cause product softening. A preliminary recommendation was to pasteurize brine at 175°F for 30 sec. Based upon data on inactivation of a heat stable commercial pectinase from *Aspergillus niger* this treatment appeared to be marginally adequate (3). The inactivation of enzyme at high pH had received limited investigation. It was decided to raise the pH of brine to 11.0 with NaOH and hold it at this pH for 24-48 hr.

Studies of the thermal inactivation of pectinases from eight fungal species reported to be commonly present on cucumbers and flowers (4) showed that pectinase from *Penicillium janthinellum* was the most heat stable among those investigated (5). Detailed studies of the effect of pH and salt concentration on the stability of this enzyme led to the conclusion that pasteurization of brine at 175°F for 30 sec is sufficient to assure pectinase free brine over the range of salt and pH conditions which are likely to be encountered in commercial practice (5). It was recommended that the pH of pasteurized brine be adjusted to near 4.5 with NaOH just prior to use.

Denaturation studies of *P. janthinellum* pectinase at high pH showed complex denaturation kinetics. This result contrasted with the results of the thermal inactivation studies between pH 3.0 and 4.7 in which first order kinetics were observed. To estimate the time required for chemical treatment in spent brine denaturation experiments were done at a series of pH values and the time required for 90% or 99% inactivation of the enzymatic activity was determined (Table 1). To assure destruction of at least 99% of the initial enzyme activity it is necessary that the brine be held at 72°F or higher, that the pH is 11.0 or higher and that the time of treatment is at least 36 hr. After treatment at high pH, the brine is adjusted to a pH near 4.5 by addition of vinegar (acetic acid).

The pectinase activity in recycled brines before and after treatment and the activity in brine samples taken from fermentation tanks at the time cucumbers were removed were measured according to the procedure of Bell *et al.* (6). No significant pectinase activity was found in these samples. As a result it is not possible to evaluate the effect of brine treatment procedures on pectinase activity "naturally" present in the brines. This was not unexpected since enzymatic softening is relatively rare in Michigan and the fermented cucumbers obtained in these experiments were of normal firmness.

TABLE 1. INACTIVATION OF PECTINASE FROM PENICILLIUM JANTHINELLUM AT HIGH PH IN SPENT BRINE. TEMPERATURE 22°C (71.6°F). SALT CONCENTRATION 8.0%

pH of incubation	Time for 90% inactivation (hr)	Time for 99% inactivation (hr)
10.6	50% inactivation in 70 hr	
11.0	21	34
11.2	5.0	37
11.3	6.5	27
11.6	2.5	13 (est)

On the scale that chemical treatment was practiced no large equipment was required. Brine samples were titrated and the amount of vinegar or NaOH required for pH adjustment of a tank were calculated. Vinegar (30% acetic acid) was added as a liquid. Sodium hydroxide was added as pellets by a person dressed in a protective rubber suit with mask and gloves.

Pasteurization of brine was done with a portable APV titanium alloy heat exchanger which was developed for this application. This was a regenerative heat exchanger heated by propane gas. The exchanger was set to heat brine at 190°F with a holding time of 30 sec. Under these conditions brine was treated at a rate of 50 gal/min.

Design of the Commercial Evaluation of Brine Recycling

Figure 2 shows the path of brine through three fermentation cycles. The project began in 1975 with the segregation of 1st cycle spent brine from the general tankyard brines. After pasteurization or chemical treatment it was used for 2nd cycle fermentations in 1975. The 2nd cycle brine was saved and treated in the spring of 1976 and used for 3rd cycle fermentations. Control fermentations in which cucumbers were covered with fresh salt brine were run in both 1975 and 1976.

Samples of brines and cucumbers were taken at appropriate points and analyzed to determine the effects of using recycled brine.

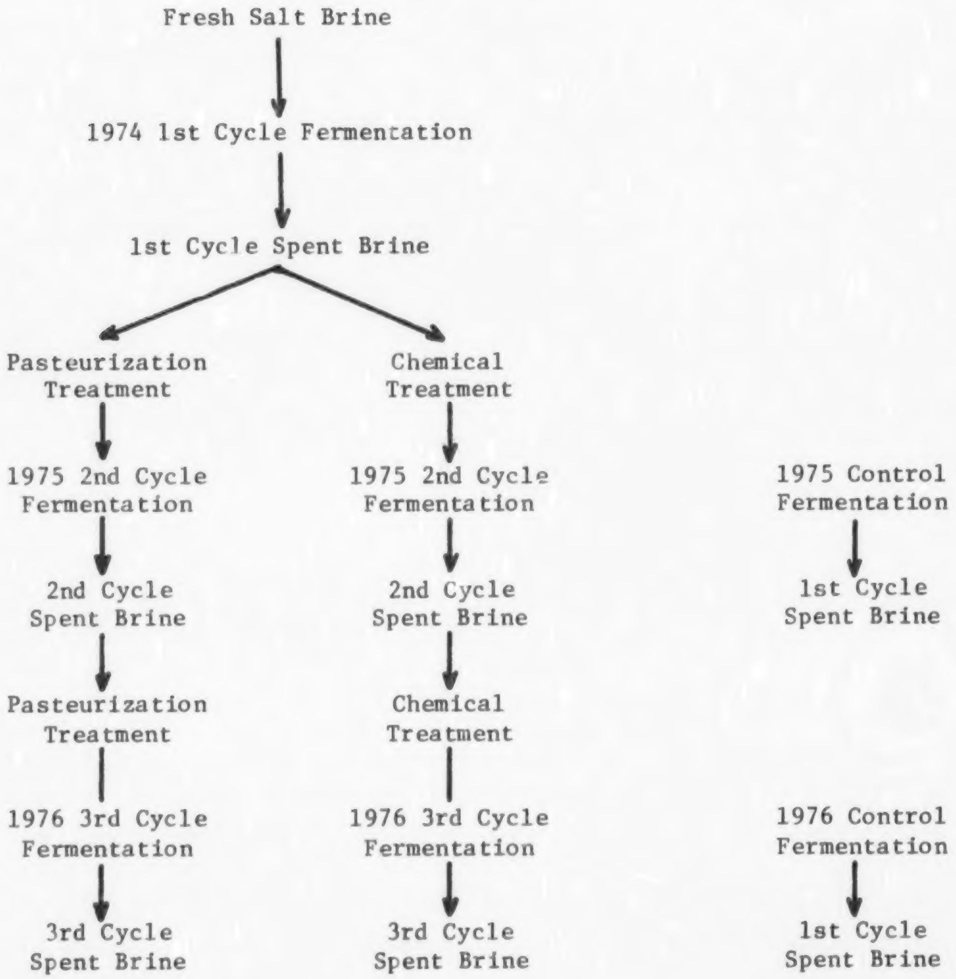
Fresh Salt Brine
1974 1st Cycle Fermentation
1st Cycle Spent Brine
Pasteurization Treatment
Chemical Treatment
1975 2nd Cycle Fermentation
1975 2nd Cycle Fermentation
1975 Control Fermentation
2nd Cycle Spent Brine
2nd Cycle Spent Brine
1st Cycle Spent Brine
Pasteurization Treatment
Chemical Treatment
1976 3rd Cycle Fermentation
1976 3rd Cycle Fermentation
1976 Control Fermentation
3rd Cycle Spent Brine
3rd Cycle Spent Brine
1st Cycle Spent Brine

Figure 2. General design of the commercial evaluation of brine recycling.

Changes in Recycled Brines

Table 2 shows the effect of pasteurization treatment on first cycle (1975) and second cycle (1976) spent brines. The rise in pH and the decrease in titratable acidity are the expected results of NaOH addition. Salt and BOD would not be expected to change significantly as a result of pasteurization treatment. There is an increase in BOD from the first to the second cycle.

TABLE 2. ANALYSIS OF SPENT BRINES BEFORE AND AFTER PASTEURIZATION TREATMENT AND PH ADJUSTMENT

	1st cycle brine		2nd cycle brine	
	initial	treated	initial	treated
Acidity (%)	0.41	0.17	0.62	0.21
pH	3.56	4.57	3.52	4.54
Salt (%)	12.5	12.6	11.4	11.8
BOD (ppm)	10,000	9,900	12,500	14,000

Table 3 shows the corresponding data on the effect of chemical treatment. Similar changes in pH and titratable acidity were observed. Since vinegar is added to drop the pH, there is an increase in BOD of about 3,000 ppm after treatment. Like the pasteurized brines there is some increase in BOD between the first and second cycle.

TABLE 3. ANALYSIS OF SPENT BRINES BEFORE AND AFTER CHEMICAL TREATMENT

	1st cycle brine		2nd cycle brine	
	initial	treated	initial	treated
Acidity (%)	0.47	0.23	0.63	0.33
pH	3.50	4.38	3.66	4.83
Salt (%)	12.8	12.8	11.1	10.8
BOD (ppm)	10,100	13,000	14,500	17,400

Chemical Use with Brine Treatment

Table 4 shows the chemical use with pasteurization or chemical treatment of the brine. The pasteurization process requires propane for the heat exchanger and NaOH for pH adjustment from the original brine pH to pH 4.5. Nearly a doubling of the NaOH required for pH adjustment of pasteurized brine occurred between 1975 and 1976. Data obtained independently on experimental tanks, a complete tankyard operation and analysis of spent brine titration curves (3) all indicated a requirement of about 14 lb NaOH/1000 gal of brine. Therefore, the 1975 result is believed to be incorrect. Chemical treatment results in use of greater amounts of NaOH to raise the pH above 11 plus acetic acid to drop the pH back to 4.5. There was an increase in the use of both NaOH and vinegar in 1976 compared to 1975.

TABLE 4. CHEMICAL USE FOR BRINE TREATMENTS PER 1000 GALLONS OF TREATED BRINE

Material	Pasteurization Treatment		Chemical Treatment	
	1975	1976	1975	1976
NaOH (lb)	7.5	14	44	52
Acetic acid (lb)	0	0	30	36
Propane (gal)	4.8		0	0

In the treatment operations about a 5% loss occurs in the pasteurization process as a result of discarding a few inches of sludge in the bottom of brine tanks which contain too much dirt, seeds and broken cucumbers to risk plugging the screen on the pasteurizer. For chemical treatment a 17% loss of brine was found. This occurs because a precipitate is formed which settles as a sludge layer. Care was taken to pump off the clear layer without disturbing the sludge layer. However, it is likely that this loss can be reduced to perhaps 10% in commercial operation without great difficulty.

An economic analysis of brine treatment is very much dependent upon the costs associated with a particular locality. Tables 5-7 show an analysis of the particular situation encountered in this project. Table 5 shows the savings realized from not discarding spent brine. The variation in the cost of BOD treatment in different localities would be the most significant variable in the overall savings. There are almost exactly 100 lb BOD/1000 gal of spent brine. Therefore, a change of one cent in the cost of BOD treatment translates in a $1.00/1000 gal change in treatment costs.

Table 6 shows the evaluation of costs for chemical treatment. The labor cost was difficult to evaluate based upon the small scale of the operation. Since the time required is intermittent rather than continuous as is the case with the pasteurization operation, the labor cost for chemical treatment was estimated to be 50% of the labor cost for pasteurization. The major costs are NaOH and vinegar. There was a net cost for chemical treatment in both 1975 and 1976.

TABLE 5. SAVINGS FROM RECYCLING 1000 GALLONS OF SPENT BRINE

	Dollars Saved
NaCl, 1.08 lb/gal @ $20/ton	10.76
BOD, 12,000 ppm at $0.08/lb	8.00
Water, $0.47/1000 gal	.45
Total Savings	19.21

TABLE 6. ECONOMIC EVALUATION OF CHEMICAL TREATMENT OF SPENT BRINES

	1975 Cost (dollars/1000 gal)	1976 Cost (dollars/1000 gal)
Labor	0.84	1.32
NaOH, 1975 19.5¢/lb 1976 17¢/lb	8.58	8.96
Vinegar, 1975 101¢/gal 1976 94¢/gal	11.87	13.32
Total Cost	21.29	23.60
Total Savings	19.21	19.21
Net Cost	2.08	4.39

Table 7 shows a similar analysis for the pasteurization process. These data are based upon full-scale commercial operation. A person is assigned to continuously monitor the pasteurizer operation. Some additional time is required to adjust the pH of the pasteurized brine to 4.5. Propane is used as fuel for the pasteurizer. The pumping cost includes gasoline plus estimates of pump maintenance. The pasteurizer depreciation is the major cost of treatment. This cost is highly dependent upon the number of gallons of brine treated. In 1975 1.2 million gallons were treated. In 1976 this decreased to 0.85 million gallons with a corresponding increase in the cost/1000 gallons. The manufacturer has estimated a life span of 20 million gallons for the pasteurizer. No pasteurizer has been in use long enough to test this estimate. However, if the estimate were correct, the cost of the pasteurizer would be $2.23/1000 gal. Based upon the actual use and a 5 yr depreciation period a substantial net savings was obtained in 1975. In 1976, with the pasteurizer cost/1000 gal substantially increased, the net savings was much smaller.

TABLE 7. ECONOMIC EVALUATION OF PASTEURIZATION TREATMENT OF SPENT BRINES

	1975 Cost (dollars/1000 gal)	1976 Cost (dollars/1000 gal)
Labor @ $4.00/hr	1.67	2.64
Propane	1.23	1.29
Pumping	0.71	0.71
NaOH, 1975 19.5¢/lb 1976, 17¢/lb	2.76	2.41
Pasteurizer 5 yr depreciation 8915/yr	6.37	10.51
Total Cost	12.74	17.56
Total Savings	19.21	19.21
Net Savings	6.47	1.65

Characteristics of the Fermentations

Tables 8 and 9 show summaries of the number of tanks operated in the project, the amount of cucumbers and the amount of brine used. The control tanks were covered with 6.6% NaCl brines at the beginning of fermentation. This follows recommendations of Etchells (7) for cucumber fermentation. Recycled brines were used at the salt concentration present after treatment, approximately 11-12%. The use of a high salt cover brine is a necessary aspect of recycling since a 2-fold dilution to 6.6% would make it necessary to discard a large fraction of the spent brine because excess brine volume would be generated.

Cucumbers were held at 6.6% NaCl during fermentation. The additional salt required to maintain this salt concentration as the cucumbers equilibrated with the brine was added as dry salt on the top of the tank headboards.

TABLE 8. SUMMARY DATA ON FERMENTATION TANKS, 1975

	Control	Heat Treatment	Chemical Treatment
No. of tanks	10	11	10
Bushels of cucumbers	7660	8668	7388
Gallons of brine	34321	31418	30881
Gallons of brine/bushel	4.48	3.62	4.18
Packout ratio	57:43	62:38	49:41

TABLE 9. SUMMARY DATA ON FERMENTATION TANKS, 1976

	Control	Heat Treatment	Chemical Treatment
No. of tanks	8	8	8
Bushels of cucumbers	5727	5604	5727
Gallons of brine	19832	20780	19960
Gallons of brine/bushel	3.46	3.71	3.49
Packout ratio	63:37	62:38	63:37

TABLE 10. FINAL PH, MAXIMUM TITRATABLE ACIDITY AND TIME REQUIRED TO COMPLETE FERMENTATIONS WITH RECYCLED BRINE, 1975

	Control	Pasteurization Treatment	Chemical Treatment
Final pH	3.23	3.33	3.44*
Maximum acidity (%)	0.80	0.92*	0.97*
Completion of fermentation (days)	17.1	16.0	15.1
Reducing sugar (%)	.035	.042	.032

*Significantly different from control at $p \leq 0.01$ level.

TABLE 11. FINAL PH, MAXIMUM TITRATABLE ACIDITY AND TIME REQUIRED TO COMPLETE FERMENTATIONS WITH RECYCLED BRINE, 1976

	Control	Pasteurization Treatment	Chemical Treatment
Final pH	3.55	3.65**	3.72*
Maximum acidity (%)	0.79	0.87*	0.98*
Completion of fermentation (days)	19.8	15.0*	16.6*

*Significantly different from control at $p \leq 0.01$ level.
**Significantly different from control at $p \leq 0.05$ level.

Tables 10 and 11 show summaries of the characteristics of fermentations in recycled brines. There are several statistically significant differences between control fermentations and recycled brines. First, the final pH of the fermentations are higher with recycled brines. The chemically treated brine was approximately 0.2 pH units higher than the control in both 1975 and 1976. The pasteurized brine is 0.1 pH unit higher. This difference was statistically significant in 1976, but not in 1975. The average final pH values were about 0.3 units higher in 1975 than 1976. The reason for this difference is not known. The titratable acidity is higher in the recycled brines. This is not unexpected since there is significant titratable acidity in the treated brines (Tables 2 and 3). The average time of fermentation was significantly shorter in 1976, but not in 1975. This is a result of a longer time for the control fermentations in 1976.

Despite some differences which are statistically significant, the changes observed would not be significant from the standpoint of actual tankyard operations. These data and the observations of tankyard operations using recycled brines show that recycling can be done with no changes in the tankyard operations during the fermentation period.

The data in tables 12 and 13 show the salt stock quality in 1975 and 1976. Good stock is that with no visible defects. Commercially acceptable stock includes the good stock plus cucumbers with slight defects which do not significantly decrease the economic value of the product. Commercially unacceptable stock is that with major bloater or honeycomb defects such that the cucumbers are suitable only for relish products.

In 1975, the quality of the salt stock was equivalent to that of the control. In 1976, the percentage of commercially unacceptable stock was somewhat higher in recycled brines. However, the differences were not statistically significant. There was a large decline in good stock in 1976. This was attributed to a higher percentage of defects in the fresh fruit.

TABLE 12. SALT STOCK QUALITY OF CUCUMBERS FERMENTED IN RECYCLED BRINES, 1975

	Control	Pasteurization Treatment	Chemical Treatment
Good stock (%)	72.8	72.8	73.0
Commercially acceptable (%)	85.3	86.5	86.5
Commercially unacceptable (%)	14.7	13.5	13.5

No significant differences among treatments.

TABLE 13. SALT STOCK QUALITY OF CUCUMBERS FERMENTED IN RECYCLED BRINES, 1976

	Control	Pasteurization Treatment	Chemical Treatment
Good stock (%)	52.1	46.0	54.0
Commercially acceptable (%)	84.9	80.2	82.6
Commercially unacceptable (%)	15.1	19.9	17.4

No significant differences among treatments.

These tanks were not gas purged. Based upon the data of Costilow *et al.* (8), it would be expected that the level commercially unacceptable fruit could be significantly reduced by power application of a side-arm purging system.

The texture of the salt stock was not significantly different from the controls. Commercial production and sale of cucumbers fermented in recycled brines indicates no detectable differences in the flavor of products produced from these cucumbers.

Table 14 shows the results of analysis for 12 elements in cucumber salt stock, desalted cucumbers and spent brine from the 1975 commercial recycling experiment. At the 0.05 level of significance there were few differences between recycled and control spent brines, salt stock or desalted cucumbers. Among the heavy metals only Pb showed any significant differences. The control salt stock averaged about 0.2 ppm higher than the salt stock from pasteurized brine. This was significant at the 0.05 level. After desalting, the control cucumbers were lower than the cucumbers from recycled brines. However, the differences were not significant at the 0.05 level.

TABLE 14. EFFECT OF BRINE RECYCLING ON THE DISTRIBUTION OF MINERAL LEVELS IN COMMERCIAL SALT STOCK, DESALTED CUCUMBERS AND SPENT BRINES. CONCENTRATIONS ARE EXPRESSED IN PPM ON A FRESH WEIGHT BASIS. 1975

Samples	Pb	Cd	Hg	P	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Salt Stock Cucumbers												
Control	.93	.057	.006	130	924	134	1.7	9.5	1.1	1.4	3.3	7.2
Pasteurization Treatment	.69	.032	.009	145	920	136	1.8	13	1.3	1.5	3.4	11.5
Chemical Treatment	.83	.061	.019	136	992	113	2.4	11	1.6	1.6	4.1	8.4
Desalted Cucumbers												
Control	.48	.039	.015	56	372	59	.06	6.1	.65	.59	.26	7.0
Pasteurization Treatment	.82	.081	.019	58	327	56	.29	7.8	.72	.59	1.2	7.1
Chemical Treatment	.76	.064	.009	53	331	53	.06	6.0	.63	.58	.18	4.9
Spent Brines												
Control	.18	.008	0	128	1130	137	3.0	8.9	2.9	1.3	4.3	7.3
Pasteurization Treatment	.18	.006	0	134	1180	142	3.1	10	1.8	1.4	4.7	12.6
Chemical Treatment	.18	.005	.001	127	1120	120	2.3	11	1.3	1.3	3.9	9.9

Tables 15 and 16 show 1975 data for the distribution of carbaryl and endosulfan in cucumbers and brines when cucumbers were sprayed in the field with twice the prescribed levels of these materials. These cucumbers were fermented under laboratory conditions.

Three cycles of fermentation were completed with control cucumbers covered with fresh salt brine. The brines for recycling were given the appropriate treatment after each fermentation. Analysis of cucumbers and brines prior to treatment and brines after treatment were done. The results do not show buildup of endosulfan in the second cycle. There is an increase of 1.1 ppm of carbaryl in the cucumbers fermented in pasteurized brine. This is probably a result of a 0.6 ppm residue in the first cycle brine after treatment.

Very low initial levels of carbaryl and endosulfan were present in the fresh cucumbers for the third cycle as a result of rain shortly after spraying. The presence of carbaryl in brine after the second cycle pasteurization treatment resulted in 0.5 ppm of carbaryl in the third cycle cucumbers.

The endosulfan is an example of a substance which remains primarily in the cucumbers. As a result, if it enters fermentation vats on cucumbers, it should be removed with the salt stock and not cause significant buildup in the recycled brine. The pattern of parathion distribution is similar to endosulfan. A significant proportion of the carbaryl diffuses into the brine. Therefore, if cucumbers are put into tanks with excessive levels, it may be possible to have significant contamination of the next batch of cucumbers. The high pH chemical treatment of brine caused breakdown of carbaryl, endosulfan and parathion.

DISCUSSION

The use of fermentation brines for 3 cycles of fermentation shows no differences between fermentations in recycled brines and those carried out in control brines. The differences observed in pH, titratable acidity and time of fermentation would not alter the way in which fermentations are carried out. The salt stock produced by recycling is equal to that obtained in control fermentations. There have been no differences between the cucumbers obtained from pasteurized vs chemically treated brine which indicate any preference for either treatment method.

The pasteurization treatment will allow about 95% recovery of brine. Chemical treatment will result in a somewhat higher loss of brine, but a recovery of 90% is feasible. The chemical treatment did degrade the pesticide residues of those materials tested in this project, while the pasteurization treatment did not. Other than these two factors it appears that selection of either of the brine recycling procedures test can be made on the basis of economic factors. Economic analysis of the two treatment procedures show a small net savings for the pasteurization treatment. This saving could be quite substantial if the pasteurizer is used to capacity and if the useful life of the pasteurizer proves to be equal to advance predictions. The chemical treatment shows a net cost. This major factor in reducing this cost would be to use less expensive chemicals or to decrease the amount of chemicals utilized. Chemical treatment does not require any large capital investments.

TABLE 15. CARBARYL LEVELS IN TREATED CUCUMBERS AND FERMENTATION BRINES. RESULTS ARE EXPRESSED AS PPM ON A FRESH WEIGHT BASIS. 1975

Cycle	Sample	Cucumbers	Control After Fermentation	Pasteurization Treatment	Chemical Treatment
1	Cucumbers	3.0	2.7	2.3	2.4
2	Cucumbers	5.5	2.5	3.6	2.5
3	Cucumbers	0.1	Tr	0.5	Tr
1	Untreated Brine		1.0	0.6	0.8
2	Untreated Brine		1.2	1.4	1.3
3	Untreated Brine		Tr	.14	Tr
1	Treated Brine			0.6	0
2	Treated Brine			1.5	0

TABLE 16. ENDOSULFAN LEVELS IN TREATED CUCUMBERS AND FERMENTATION BRINES. RESULTS ARE EXPRESSED AS PPM ON A FRESH WEIGHT BASIS. 1975

Cycle	Sample	Fresh Unwashed Cucumbers	Control After Fermentation	Pasteurization Treatment	Chemical Treatment
1	Cucumbers	.31	.43	.42	.37
2	Cucumbers	.36	.34	.35	.31
3	Cucumbers	.05	.06	.07	.08
1	Untreated Brine		.012	.005	.019
2	Untreated Brine		.013	.028	.013
3	Untreated Brine		0	.002	.001
1	Treated Brine			.004	0
2	Treated Brine			.017	0

Data on the potential buildup of toxic substances in cucumbers as a result of recycling is not yet completed. Results of 1975 experiments do not indicate any buildup of compounds as a result of recycling which would limit the application of recycling procedures. However, final conclusions cannot be made until analysis of the second year of data is completed.

REFERENCES

1. Geisman, J.R. and Henne, R.E. Recycling food brine eliminates pollution. Food Engr. 45(1):119 (1973).

2. Geisman, J.R. and Henne, R.E. Recycling brine from pickling. Ohio Report 58:76 (1973).

3. Palnitkar, M.P. and McFeeters, R.F. Recycling spent brines in cucumber fermentations. J. Food Sci. 40:1311 (1975).

4. Etchells, J.L., Bell, T.A., Monroe, R.J., Masley, P.M. and Demain, A.L. Populations and softening enzyme activity of filamentous fungi on flowers, ovaries, and fruit of pickling cucumbers. Appl. Microbiol. 6:427 (1958).

5. Chavana, S. and McFeeters, R.F. Thermal inactivation of fungal pectinases in cucumber brines. Lebensmittel-Wissenschaft Tech. (in press).

6. Bell, T.A., Etchells, J.L. and Jones, I.D. A method for testing cucumber salt-stock for softening activity. U.S. Dept. Agr., ARS-72-5 (1955).

7. Etchells, J.L. and Moore, W.R. 1971. Factors influencing the brining of pickling cucumbers--Questions and answers. Pickle Pak Science 1:1 (1971).

8. Costilow, R.N., Bedford, C.L., Mingus, D. and Black, D. Purging of natural salt-stock pickle fermentations to reduce bloater damage. J. Food Sci. 42:234 (1977).

TREATMENT OF PACKINGHOUSE WASTEWATER BY SAND FILTRATION

by

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INTRODUCTION

During the past five years the W. E. Reeves Packing Plant in Ada, Oklahoma has been used as the site for a number of wastewater treatment investigations. These investigations have been conducted as a cooperative effort of the Reeves' company, East Central Oklahoma State University, and the Environmental Protection Agency. The research conducted at the site has been funded by contracts and grants from the Environmental Protection Agency, Food and Wood Products Branch, Corvallis, Oregon.

The investigations conducted at the Reeves' facility have been directed toward finding treatment methods which are economically feasible and simple to operate and maintain, but which also produce a discharge which will meet effluent guidelines. Earlier publications by Witherow (1) (2) reveal the results of aerobic and anaerobic lagoon treatment, extended aeration lagoon treatment, and overland flow irrigation.

However, there is a need for a variety of proven treatment methods which can be reviewed by management, for each plant operator must consider the cost, volume and concentration of wastewater, land requirements, climatic conditions, etc. in order that the best method of treatment can be selected for each plant. This paper will be concerned with the treatment of meatpacking wastewater by intermittent sand filtration.

HISTORY OF SAND FILTRATION

The use of sand filtration for the treatment of water and wastewater is not a recent innovation in the United States. A survey of the literature reveals the existence of sand filtration for the improvement of drinking water supplies in the United States as early as 1828 (3). Much of its use and further development immediately following the introduction of the sand filter took place in Europe. However, the population growth in the United States, especially in the eastern cities of the United States, created a demand for larger volumes of drinking water and around the turn of the century, a number of slow sand filter units were in use in the United States for the treatment of drinking water supplies.

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Just as the population growth in the United States had created a demand for methods of treating larger volumes of drinking water, the need arose for methods of treating the increasing volumes of wastewater produced by the municipalities. An experimental intermittent sand filter unit for the treatment of domestic wastewater was built in Lawrence, Massachusetts in 1888 (4). The operation of the intermittent sand filter unit proved successful. However, a rapid increase in the number of sand filter units for the treatment of sewage was not experienced in the United States until the 1940's. The limiting factors for the increased usage of intermittent sand filter units were apparently the availability of natural sand sources meeting the desired specifications and the requirement of large tracts of land.

Following World War II, the rapidly increasing number of subdivisions, mobile home parks, and resort areas in Florida created a need for economical and practical treatment systems which would produce an effluent of suitable quality. This need for simple and economical sewage treatment units for small volumes of wastewater led investigators at the University of Florida to test various designs for intermittent sand filter units (4). Much of the present knowledge concerning intermittent sand filters has come from these early studies at the University of Florida.

The early designs of intermittent sand filters have seen little change over the years that they have been in use. The units usually consist of an underdrain of open-jointed tile or perforated pipe. The underdrain network is covered with approximately 18 inches of gravel ranging from 1/8 to 3 inches in diameter. Filter sand is placed on the gravel at a depth that varies from 24 to 60 inches. In the design of an intermittent sand filter, emphasis must be placed on sand specifications. It must be a well graded sand with the proper effective size and uniformity coefficient. The effective size is usually between 0.15 and .35 mm, and the uniformity coefficient is usually less than 3.0. Hydraulic loading rates for sand filters vary depending on the filter media and the amount of suspended solids in the raw wastewater. All of these factors must be considered in order to design a filter unit capable of experiencing a feasible period of operation before clogging of the filter media occurs.

In the past few years, workers have demonstrated the effectiveness of intermittent sand filters in reducing the suspended solids values of domestic waste which has received prior treatment in lagoon systems. Evidence of the effectiveness of intermittent sand filters for the reduction of suspended solids can be found in the published works of Reynolds (5), Marshall (6), and Walter (7). Other supportive evidence for intermittent sand filters as a means of lowering suspended solids values can be found in reports by Grantham (8) and Furman (9).

PILOT SCALE OPERATION

A review of the work by the authors cited above led Witherow and Rowe to consider the use of intermittent sand filters as a means of polishing the wastewaters from the lagoons at the W. E. Reeves Packing Company in Ada, Oklahoma. Other investigations were being conducted at these treatment facilities at that time which made evaluation of pilot scale intermittent sand filter units feasible.

Two pilot scale units were constructed in close proximity to the treatment system. Each unit was formed by welding two 55-gallon barrels end-to-end. Effluent lines were installed in the bottom of the units and each unit was filled with gravel and sand to serve as the filter media.

The pilot scale filter units contained 18 inches of gravel, ranging from 0.25 to 1.25 inches in diameter, with the larger gravel particles in the bottom of the unit. The gravel was then covered with 36 inches of sand which had an effective diameter of 0.2 millimeters (mm). Investigations were then conducted by applying wastewater from the extended aeration lagoon and the secondary aerobic lagoon to the filter units at a rate equivalent to 0.5 million gallons per acre per day (mgad).

Analysis of the influent and effluent samples collected during the pilot scale study revealed a 5-day Biochemical Oxygen Demand (BOD_5) removal of approximately 70 percent and a suspended solids reduction of approximately 50 percent. The concentrations of BOD_5 and suspended solids in the effluent from the pilot units were converted to lbs/1000 lbs of Live Weight Kill (LWK) and compared to the Best Practical Treatment (BPT) and Best Available Treatment (BAT) guidelines for small packinghouses. The results showed that the effluent from the filter units could meet the suspended solids limits for BPT and BAT guidelines. All BOD_5 samples from the pilot units were below the BPT values and only one was slightly in excess of the BAT guidelines. The results of the pilot scale study led to the development of the large scale project at the W. E. Reeves' facilities.

PRELIMINARY DESIGN

Since the treatment facilities had been used for previous investigations, information pertaining to the daily volume of wastewater from the plant and the concentration of various pollutants in the wastewater was readily available to the investigator. The investigator also had access to information pertaining to the average suspended solids concentration and average BOD_5 values of the effluent from the extended aeration lagoon and the secondary aerobic lagoon in use at the treatment facilities. Other information pertaining to sand and gravel specifications, recommended loading rates onto the filters, filter design, etc. were available from the literature and the pilot study previously conducted by the investigator. All of this information was used in developing the preliminary design of the filter units.

The preliminary design for the filter project was based on an average wastewater flow of 18,000 gallons per day with a maximum daily flow of 30,000 gallons. During preliminary design, a site adjacent to the existing lagoon system was selected for the proposed sand filter units so that loading from either the extended aeration lagoon or the secondary aerobic lagoon would be possible by gravity flow. The proposed site for the sand filter units also had the advantage of providing a means of diverting the flow from the filters to the existing lagoons in case of an accidental spill or necessary filter repairs. Figure 1 shows the layout of the facilities.

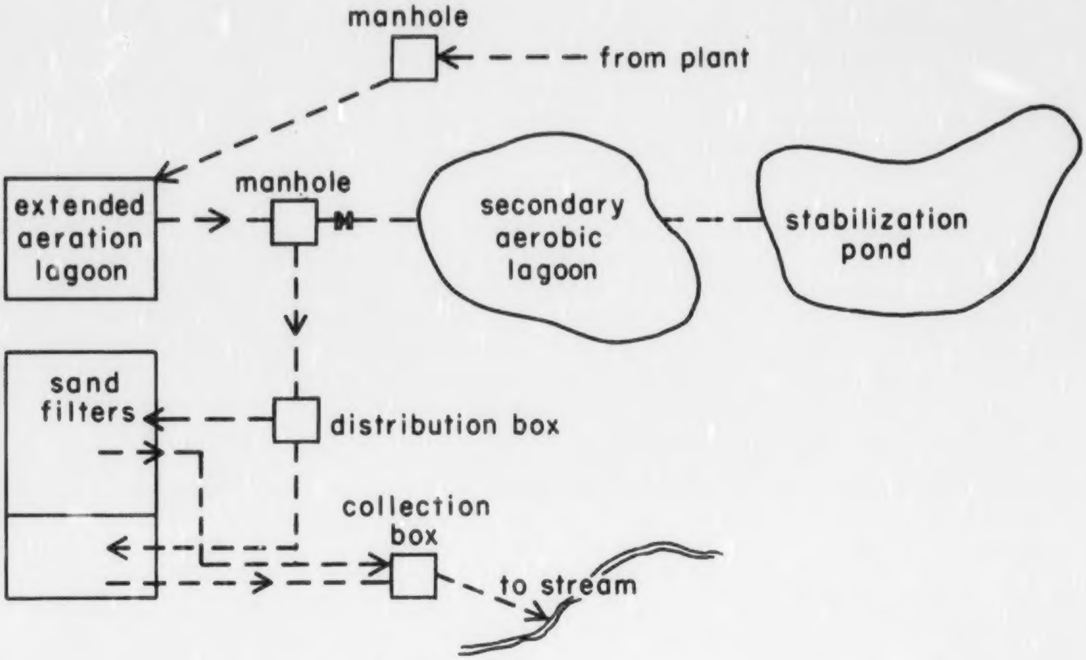

Figure 1. W. E. Reeves' Treatment Facilities.

During the planning of the project, it was decided that instead of one filter unit, two small units of unequal size should be constructed. This would offer the advantage of having two different surface areas for the purpose of investigating different hydraulic loadings and would have the added advantage of providing one operable filter to be used while the second was being cleaned.

By following the recommendations for the bottom dimensions, slope of interior dike, and depth of sand gravel, the completed structure consisted of two filter units with sand surface areas of approximately 880 and 1220 square feet. When a wastewater flow of 18,000 gallons was applied to the small sand filter, the hydraulic loading would be 0.90 mgad, and with one-half of this average day flow onto the small filter, the resulting hydraulic load would be 0.45 mgad. Corresponding loading rates of 0.64 and 0.32 mgad could be obtained by using the larger filter.

CONSTRUCTION

The filter units were formed by clay embankments on three sides, and the fourth side of each filter unit was formed by a common concrete wall between the two units. The purpose of the common wall was to reduce the amount of land required for the filters. Each unit would consist of 36 inches of sand over 18 inches of gravel and each filter unit would have a separate underdrain system.

The bottom of the filter units was formed of six inches of compacted clay. The bottom of each filter was sloped toward the effluent drain to insure proper drainage from the filters.

The embankments were constructed of clay and were built so that the interior of the dikes were sloped at a ratio of 2.5 horizontal units to 1.0 vertical units. The elevation from the bottom of each filter unit to the top of the dike was a minimum of 9.5 feet, thus allowing a freeboard of at least 5 feet above the surface of the sand. The tops of the embankments were 8 feet wide so that vehicles and machinery could be used at the treatment site.

A factor which determined the dimensions of the bottom of the sand filter units was the space required for the normal operation of heavy equipment, such as a dozer, during the construction phase of the project. The final specifications for the bottom of the structure called for a width of 12 feet and a length of 42 feet. After the bottom was compacted, the 6 inch concrete wall was to be poured to form two filter units with bottom dimensions of 12 feet by 14 feet and 12 feet by 28 feet respectively.

The underdrain network of each filter consisted of a series of five inch diameter perforated pipes on the bottom of the filter bed. Spacing of the pipes was approximately 3 feet, and each lateral line was connected to a six inch diameter pipe serving as the main drain from the filter unit. The main drain line projected through the walls of the dike and emptied into a sample collection box. Effluents from the filters were discharged from the collection box to the stream that runs from the Reeves' property.

A manhole already existed between the extended aeration lagoon and the secondary aerobic lagoon. A six inch line was installed from this manhole to a distribution box constructed in close proximity to the sand filters. A six inch line was then installed from the distribution box to each of the filters. By using this scheme, the wastewater from the extended aeration lagoon could be discharged to the existing secondary aerobic lagoon or to the filters via the distribution box. Wastewater from the extended aeration lagoon discharged to the distribution box could be loaded into one or both of the filters.

OPERATION

The construction of the sand filters was completed in December, 1975, and operation began in early 1976. During the early stages of operation, many mechanical problems were experienced with the timers and valves, but these difficulties were corrected and routine monitoring of the system began in March, 1976.

The monitoring operation consisted of the collection and analysis of raw wastewater samples, effluent from the extended aeration lagoon, and effluent from the filter units. Composite samples of the raw wastewater and lagoon effluent were collected, but grab samples were collected from the sand filters.

The extended aeration process was in a single lagoon and operated in a batch mode. The aerator in the lagoon was operated from 9:00 a.m. to 11:00 p.m. Solids in the lagoon settled for five hours and then at 4:00 a.m. a hydraulic valve was activated discharging the supernatent from the lagoon to the filters. The valve automatically closed after four hours.

During the first part of this investigation, March until September, the filter media in the filters consisted of washed sand with an effective diameter of

0.2 mm and a uniformity coefficient of 4. While this sand was in use the length of filter runs was unsatisfactory. Loading rates of 0.55 mgad and 0.86 mgad were evaluated in this portion of the study. For the loading rates of 0.55 mgad and 0.86 mgad, the average length of filter runs was 15 and 10 days respectively. The filter run was the length of time from the first loading of a filter to the time the filter was plugged and the filter was considered plugged when the water loaded onto a filter remained on the filter surface for more than 24 hours.

In an attempt to increase the length of filter runs, the original sand was removed from the filter and replaced with sand having a uniformity coefficient of 2.5 and an effective diameter of 0.35 mm. Also, the hydraulic loading was reduced to 0.36 mgad. The increased sand size and the reduced hydraulic load lengthened the filter run to 109 days. This portion of the study was conducted during the period of time from October until late February. The results are shown in Table 1.

TABLE 1. LENGTH OF FILTER RUNS

Loading Rate (MGAD)	Sand		Mean Filter Runs	
	(Eff. Dia.)	(Unif. Coeff.)	(Days)	(Number of Runs)
0.86	0.20 mm	4.0	10	5
0.55	0.20 mm	4.0	15	6
0.36	0.35 mm	2.5	109	1

RESULTS

The wastewater samples collected during the investigation were analyzed for a number of parameters. However, only the results for those parameters which are of most concern to meat packers are presented in this paper. These parameters include BOD_5, Total Suspended Solids (TSS), Fats, Oil and Grease (FOG), Ammonia Nitrogen (NH_3-N), and fecal coliform. Table 2 lists the average concentration for each of these parameters for the raw wastewater, extended aeration lagoon, and sand filter effluent. This table also includes the reduction which was accomplished for each of these parameters by the treatment system. The average flow for the project period was 19,756 gallons per day and the average live weight kill was 24,617 lbs/day.

TABLE 2. SAND FILTRATION PROJECT
Wastewater Characteristics and Percent Removal

Parameters	Num.	Raw Waste.	Num.	Ext. Aer. Eff.	Num.	Filter Eff.	Percent Removal
BOD_5 (mg/l)	46	672.0	51	31.0	57	10.4	98.5
TSS (mg/l)	27	392.0	43	41.0	63	11.1	97.1
FOG (mg/l)	16	138.7	10	29.1	10	<5.0	>96.4
NH_3-N (mg/l)	16	14.8	14	3.1	14	1.9	87.2
Fecal Coli. (MPN/100 ml)					37	1.88×10^4	

During the investigation, a sand with a uniformity coefficient of 4 was used at hydraulic loading rates of 0.86 mgad and 0.55 mgad. Also, one sand source with a uniformity coefficient of 2.5 was used with a hydraulic loading of 0.36 mgad. The average values for BOD_5, TSS, NH_3-N, fecal coliform, and FOG are listed in Table 3.

Table 4 gives a comparison of the test results to the 1977 (BPT) and 1983 (BAT) guidelines for small packinghouses. The pH and fecal coliform values are not presented in the table. All pH values of effluent from the sand filters were between the pH limits of 6 to 9 units with an average pH value of 7.4. A total of 56 pH readings were taken. All coliform values for the sand filter effluent exceeded the 400 MPN/100 ml limit with the exception of a one-day value.

The effluents from the sand filter units meet the 1977 (BPT) guidelines for 30-day average and maximum day average for BOD_5, TSS, and FOG. Also, the new source limitations for ammonia nitrogen were met.

The 1983 (BAT) limitations were met for FOG. However, the effluent did not meet the BOD_5 and TSS limitations. An examination of Test B (Table 4) reveals that the 30-day average and maximum day average for BOD_5 were slightly exceeded. Also, the TSS values of the effluent slightly exceeded the 30-day average, but did meet the maximum day limitation. Test B was conducted between October 21, 1976 to February 23, 1977 and only eight TSS values and 10 BOD_5 values were collected. A longer evaluation is recommended.

COST

One of the objectives of the project was to develop a treatment system which would be economical to construct and maintain, and one which would be simple to operate.

TABLE 3. RESULTS OF TESTS

Parameters	Num.	0.86 MGAD Sand A	Num.	0.55 MGAD Sand A	Num.	0.36 MGAD Sand B	Num.	Combined Data
BOD_5 (mg/1)	21	10.2	26	10.5	10	10.2	57	10.4
TSS (mg/1)	27	10.6	28	11.8	8	10.6	63	11.1
NH_3-N (mg/1)	3	2.4	6	1.9	5	1.6	14	1.9
FOG (mg/1)	1	<5.0	6	<5.0	3	<5.0	10	<5.0
Fecal Coliform (MPN/100 ml)	15	2.75×10^4	16	1.39×10^4	6	1.02×10^4	37	1.88×10^4

Sand A - uniformity coefficient of 4; effective diameter of 0.2 mm.
Sand B - uniformity coefficient of 2.5; effective diameter of 0.35 mm.

TABLE 4. COMPARISON OF TEST RESULTS AND EFFLUENT LIMITATIONS

Parameter	Packinghouse limits		Test Results A		Test Results B	
	30-day avg.	max-day	30-day avg.	max-day	30-day avg.	max-day
1977 Limitations						
BOD_5	.17	.34	.07	.17	.07	.10
TSS	.24	.45	.07	.30	.07	.11
FOG	.08	.16	<.03	<.03	<.03	<.03
New Source Limitations (include above + NH_3)						
NH_3-N	.24	.48	.01	.03	.01	.02
1983 Limitations (BAT)						
BOD_5	.04	.08	.07	.17	.07	.10
TSS	.06	.12	.07	.30	.07	.11
FOG	10 mg/1	20 mg/1	<5 mg/1	<5 mg/1	<5 mg/1	<5 mg/1

Test Results A - Data collected from filter at loading rates of 0.86 and 0.55 mgad and sand with uniformity coefficient of 4 and effective diameter of 0.2 mm.

Test Results B - Data collected from filter at loading rate of 0.36 mgad and sand with uniformity coefficient of 2.5 and effective diameter of 0.35 mm.

All values in Table 4 are in lbs/1000 lbs LWK except 1983 FOG values.

Earlier publications by Witherow (10) indicated that the cost of construction of the extended aeration lagoon, sewer, and manholes was $14,000. The sand filter units were constructed at a cost of $13,000. However none of these figures include the cost of land. Additional expenses to be considered are the cost of electricity for the aerator and maintenance cost of the aerator.

The later part of the investigations revealed that the sand filter units could be operated in excess of 90 days before clogging of the filters occurred. Based on a continuous operation of 90 days for the sand filter, annual maintenance cost of the filter should not exceed $500. This figure allows for the labor cost for four cleanings per year and also covers the sand replacement costs. These cost figures are presented in Table 5.

TABLE 5. COST OF EXTENDED AERATION AND SAND FILTRATION SYSTEM AT THE W. E. REEVES' PACKING PLANT

(a)	Sewer and Manholes	$ 2,000
(b)	Extended Aeration Lagoon	12,000
(c)	Sand Filter	13,000
(d)	Annual Maintenance of Filter	500

Note: Items (a) and (b) taken from an earlier report (10). Also, cost of land, electricity for aerator, and cost of maintenance of aerator not included.

SUMMARY

The original objectives of the project were to develop an economical treatment system capable of meeting the effluent guidelines. Cost figures presented in this study indicate that the extended aeration lagoon and intermittent sand filter system would meet the criteria of being an economical system to construct.

During the early stages of operation, the test facility required much attention and involved a great deal of manpower for frequent cleaning of the filter units. However, after the filter media and hydraulic loading rates were modified, maintenance and operational problems were minimal which indicates that the system would also be economical to operate and maintain.

The effluent from the test facility met the 1977 (BPT) effluent guidelines for all parameters, with the exception of fecal coliforms. Upon the incorporation of a disinfection system, the test facility would meet all the 1977 (BPT) effluent guidelines for small packinghouses. The effluent also met the ammonia nitrogen new source limits.

The 30-day average and maximum day average values for the 1983 (BAT) limitations with respect to BOD_5 and the 30-day average value for suspended solids were exceeded slightly. The 1983 (BAT) limitations for FOG were met.

REFERENCES

1. Witherow, J. L. Small Meat Packers Waste Treatment Systems. Proceedings of the 28th Industrial Wastes Conference, Purdue University, Lafayette, Indiana, May 1973.

2. Witherow, J. L. Small Meat Packers Waste Treatment Systems - II. Proceedings of the 30th Industrial Waste Conference, Purdue University, Lafayette, Indiana, May 1975.

3. Daniels, F. E. Operation of Intermittent Sand Filters, Sewage Works Journal 17: 1001-1006 (1945).

4. Reynolds, J. H., Harris, S. E., Hill, D. W., Filip, D. S., and Middlebrooks, E. J. Presented at EPA Technology Transfer Seminar on Wastewater Lagoons, Boise, Idaho, November 19-20, 1974.

5. Reynolds, J. H., Harris, S. E., Hill, D. W., Filip, D. S., and Middlebrooks, E. J. Intermittent Sand Filtration for Upgrading Waste Stabilization Ponds, Presented at Water Resource Symposium Number Nine, University of Texas, Austin, July 22-24, 1975.

6. Marshall, G. R., and Middlebrooks, E. J. Intermittent Sand Filtration to Upgrade Existing Wastewater Treatment Facilities, PRJEW 115-2, Utah Water Research Laboratory, College of Engineering, Logan, Utah, February, 1974.

7. Walter, C. M. Progress Report, Blue Springs Lagoon Study, Blue Springs, Missouri. Prepared for presentation at the Symposium on Upgrading Wastewater Stabilization Ponds to meet Discharge Standards, Sponsored by EPA and Utah State University, Logan, Utah, August 21-23, 1974.

8. Grantham, G. R., Emerson, D. L., and Henry, A. K. Intermittent Sand Filter Studies, Sewage Works Journal 21: 1002-1014 (1949).

9. Furman, T., Calaway, W. T., and Grantham, G. R. Intermittent Sand Filters. Multiple Loadings, Sewage and Industrial Wastes 27: 261-275 (1955).

10. Witherow, J., Tarquin, A., and Rowe, M. Manual of Practice - Waste Treatment for Small Meat or Poultry Plants, Food Processing Waste Research, EPA, Corvallis, Oregon, 1976.

ECONOMIC RETURN ON POLLUTION CONTROL EXPENDITURES FOR THE PICKLED FOOD INDUSTRY

by

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BACKGROUND

Plants which ferment, store and pack pickled food products have a significant need for wastewater control and treatment in order to comply with NPDES discharge permits and municipal sewer ordinances.

The waste can be generally characterized as high in BOD_5, TSS, Cl^- and Acid; also during periods of ordinary rainfall there is a serious contamination of stormwater run-off.

HOW DO YOU RESOLVE THESE PROBLEMS?

Detailed investigations were made of water usage and the sources of waste generation. Wastewater treatment technology was reviewed as it might apply to the nature, volume and frequency of the discharges.

INITIAL RESULTS

These studies showed that approximately 35% of water usage could be readily reduced and through the use of improved housekeeping and screening, raw waste loading could reduce by 40%.

ALAS, THE REAL SERIOUS CULPRIT SURFACES

As pickle processing plants perform more frequent and detailed wastewater characterizations and as regulatory agencies perform more frequent and detailed monitoring of receiving streams and municipal sewers, the plot thickens. It becomes abundantly clear that there is a high level of total dissolved solids, principally in the form of chlorides.

The history of regulatory agencies, both State and Federal, shows little concern for TDS or chlorides until the last two years. Even at this time there is little uniformity of action. EPA has chosen to stay out of the controversy by not establishing Effluent Limitation Guidelines for TDS or chlorides for the Flood Industry Categories. They say that this is a matter for state regulation in accordance with each state's goals for maintenance of water quality standards for individual receiving streams. This is contrary to the basic EPA philosophy of "technology - based" effluent limitation criteria.

Most states have not made definitive analyses of the impact of TDS of chlorides upon stream usage and have chosen to adopt the most restrictive use - drinking water. The municipalities, in turn, have adopted the same limitation, that for drinking water, for wastewater discharges to sanitary sewers.

Therefore, it has become apparent that several plants within the pickled food industry must drastically reduce the chloride level in their wastewater.

HOW DO YOU ACCOMPLISH THIS?

Treatment is not the answer - distillation and reverse osmossis have high capital and operating costs, land application is generally toxic to most vegetation and precipitation with silver nitrate is a little ridiculous!

What's Left? Reduce it at its source. The area which contributes approximately 75% of chlorides in the wastewater is the tank yard operation of fermentation and storage of pickles.

The two papers proceeding this one described two major efforts to reduce the use of chlorides: one by James Harris recommending chloride reductions through the use of controlled fermentation; the other by Dr. Roger McFeeters, recommending reuse of spent brines by utilizing various conditioning processes to deactivate softening enzemes and screen gross solids.

While each of these actions will drastically reduce the quantities of chlorides in wastewater, they do not address two more sources of chloride loss - those of tank leakage and stormwater overflow and run-off contamination.

Rainwater accumulating and overflowing the top of the open tanks not only causes waste problems but can be disturbing to the fermentation process.

One of Johnson & Anderson, Inc. clients was given a severe restriction of chloride discharge to the sanitary sewer. The only hope for compliance was through replacement of all leaking tanks, no overflow caused by rainwater, recycle of spent brine and possibly controlled fermentation.

HOW DO YOU DO THIS AND STAY COMPETITIVE?

Combining the research work on brining practices and some successful full scale work at a couple of plants, we applied basic process engineering techniques with generous applications of imagination. The results are shown on Figure 1, 2 and 3.

The three basic process changes that provide the opportunity for chloride reductions plus significant operating and maintenance cost reductions are:

1. Pumping of cucumbers and pickles
2. Degassification and recirculation of fermentation brine
3. Adjustment of fermentation brine constituents

These process steps open the way for the following cost reduction features:

1. Clustering of tanks, thereby reducing real estate requirements by a factor of 3.0
2. Permanently sealed tops, eliminating spillage and rainwater contamination
3. Sluicing cucumbers and pickles eliminating damaged stock
4. Uniform, accelerated and controlled fermentation
5. Reuse of spent brine
6. Elimination of many forklift trucks and tote boxes and their associated maintenance

HOW DID WE ASSESS THE ECONOMIC IMPACT?

We established the present costs for operating and maintaining the tank yard. A plant audit was performed; all cost categories were identified; overhead and indirect costs were allocated. This gave us a baseline for reference.

Then several cost categories were modified, eliminated or added, to reflect the proposed conditions. The capital costs were distributed over a three year period; depreciation and interest were distributed accordingly. The annual costs summaries yielded the required cash flow and return on investment.

DO IT YOURSELF - BASIC PROCESS CHANGE

We feel this exercise can be repeated in many food industries by considering some of the following:

1. Look at individual process steps
2. Ask, "Why do we do what we do?"
3. Should this operation be batch or continuous
4. What are the advantages of system monitoring
5. Where are the losses, the wastes

We all have a great reluctance to change. Change only occurs when there is a significant potential difference between existing and projected conditions. The greater the difference the greater the driving force, the greater the rate of change.

Crisis and subsequent threats to economic existence are excellent modivators for change. EPA and FDA are presently providing liberal applications of these modivators.

Don't fold up your tent - try the water of process change, it can be rewarding and exciting!

AN EFFECTIVE WASTEWATER MANAGEMENT PROGRAM FOR A FOOD PROCESSOR

by

George E. Wilson* and Jerry Y. C. Huang*

INTRODUCTION AND DILEMMA

The Federal Water Pollution Control Act Amendments of 1972, PL 92-500, without doubt comprise the most far reaching pollution-control legislation in history. The net effect of the new legislation in many cases means increased costs to industry for treating its wastewater discharge. Under PL 92-500, the industry is classified in two categories depending on the final destination where the wastewater effluent discharged to. The first and more complex situation is that in which industry discharges wastewater effluent to a publicly owned treatment system. This type of industry is called user industry. The other situation involves industry providing treatment of its own effluents for direct discharge to a receiving body of water. This type of industry is called direct discharger.

The comparison of the two effluent discharge categories is illustrated in Table 1. For the user industry, in which the industry discharges its wastewater effluent to a public wastewater treatment facility, there are two constraints: industrial payback provisions and pretreatment standards. Under this provision, no grant for any publicly owned treatment works has been approved since March 1, 1973, unless the applicant has met the following requirements:

a. Made provisions for payment to the applicant by industrial users of that portion of the cost of construction which is applicable to the treatment of industrial waste to the extent of the federal share of the cost of construction.

b. Adopted a system of charges such that each recipient of waste treatment services will pay its proportionate share for the cost of operation and maintenance of waste treatment services.

In addition to the repayment of the federal share, pretreatment standards are required by the local agency for introducing the pollutants into publicly owned treatment works. Therefore, the permissible effluent limits are varied depending on the requirement by the local agency.

For the direct discharger, who discharges its wastewater effluent to a receiving body of water, there are also two constraints: effluent standard

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TABLE 1. COMPARISON OF TWO EFFLUENT DISCHARGE CATEGORIES

Item	User Industry	Direct Discharger
A. Effluent discharge destination	Publicly owned system	Receiving body of water
B. Constraints	Industrial payback provisions	Effluent standards:
	Pretreatment standards	NPDES permit BPT by July 1, 1977 BAT by July 1, 1983 Zero discharge by 1985
		More stringent monitoring
C. Permissable effluent limit	Varied	Fixed

requirements and stringent monitoring requirements.

The act calls for a National Pollutant Discharge Elimination System (NPDES) which clearly states that any effluent discharge is illegal unless a permit has been issued for it. By July 1, 1977, effluent limitations for existing sources of liquid waste from industrial plants will require the application of the best practicable control technology (BPT) currently available. By July 1, 1983, effluent limitations require the application of the best available control technology (BAT) economically achievable. The act establishes zero discharge, the complete elimination of all discharges of pollutants into navigable waterways, as a national goal for 1985. The act contains stringent requirements on the establishment and maintenance of records, waste stream monitoring, sampling, and analyses.

For either type of industry, the wastewater management program objective is identical: namely,

> The development of a performance guaranteed wastewater treatment system at optimum cost.

For the user industry, the optimum cost represents the best combination of in-plant treatment of certain waste material with the remainder treated in the municipal treatment system. On the other hand, the optimum cost for the direct discharger represents the least cost system which will produce an effluent within the fixed allowable limitations.

This paper presents a phased approach for a carrot processor in developing the most cost effective wastewater management program.

WASTEWATER MANAGEMENT ALTERNATIVES

A carrot processor, processing approximately 20 tons/hr of raw carrots, cleans and transports the product hydraulically resulting in significant amounts of soil solids in the wastewater. In the past, the carrot processor discharged his wastewater directly into a nearby drainage ditch. However, in 1975, the carrot processor was issued a cease and desist order by the Regional Water Quality Control Board on the discharge of untreated wastewater to a drainage ditch. The cease and desist order required the plant effluent to have average biochemical oxygen demand (BOD) and suspended solids (SS) concentration of 20 mg/l with the maximum of 40 mg/l each. The settleable matter was limited to an average of 0.5 ml/l with the maximum of 1 ml/l.

The management alternatives were:

1. Do nothing and shut down the plant;
2. Install treatment equipment without careful engineering evaluation, thus risking failure of meeting effluent requirement;
3. Adopt a three-phase approach based on sound engineering evaluation for developing a performance guaranteed system.

The first alternative was unacceptable as the business was healthy and worth preserving. The second alternative, however, risked the failure in meeting the effluent requirement. The third alternative required time for engineering evaluations, and was guaranteed to meet the requirement. The management chose the third alternative as the one most consistent with the long range growth plans.

OBJECTIVES AND PROGRAM DEVELOPMENT

Two objectives which had to be accomplished in the wastewater management program were removal of settleable, suspended and colloidal materials from the wastewater, and reuse of the reclaimed water in product cleaning operation. Three-phase program formulated for achieving these objectives was:

Phase I - Evaluation of soil solids removal and water reuse system

Phase II - Pilot evaluation of the system for suspended and colloidal solids removal and water reuse

Phase III- Design, installation, and start-up of the full-scale solids removal and water reuse system

Phase I - Evaluation of Soil Solids Removal and Water Reuse System

A flow diagram of the Phase I water recycle and solids removal facilities is depicted in Figure 1. A submersible pump was placed at the bottom of the washwater mud pit to pump the washwater through a teacup solid separator, 4 foot diameter and handling wastewater flow of 500 gpm, for soil solids removal and hydra-vibe screen for removal of screenable vegetable material. The water was then recycled back to the mud pit. The water in the mud pit, which was free from the settleable soil solids, was reused in the product cleaning and transporting operation.

The teacup solids separator, consisting of integrated teacup separator and solid thickener compartments, has a flow regime similar to that of a stirred teacup. Solids separation is efficiently achieved within the unit by a combination of "teacup" secondary velocities, vortex, gravitational, and inertial forces of the settleable particles. No hydraulic flow occurs between the separator and the thickener, thus, the settling zone is quiescent. Separated solids are sweeped in the quiescent zone by the teacup secondary velocities. The teacup solid separator produced dense settled solids and water discharged from the teacup solids separator and the screen contained primarily colloidal material, both inorganic and organic.

The soil solids removal performance of Phase I facilities is tabulated on Table 2. The system was placed in operation on May 19 (Wednesday) at noon and continued as a closed system with no addition of make-up waters through noon Friday, May 21, 1976. Shift operations began with fresh water in the mud pit on Saturday, May 22, and on Monday, May 24, 1976.

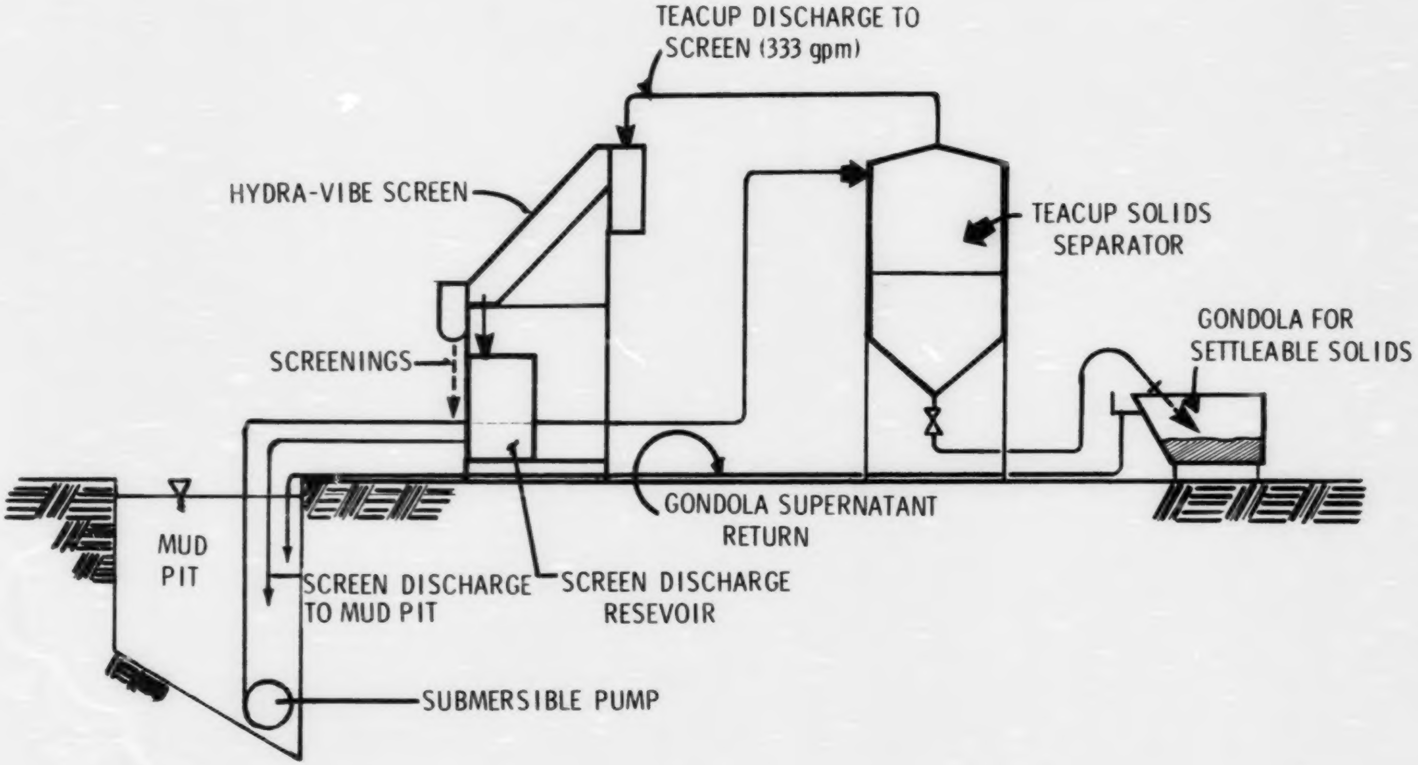
TEACUP DISCHARGE TO
SCREEN (333 gpm)
HYDRA-VIBE SCREEN
TEACUP SOLIDS
SEPARATOR
GONDOLA FOR
SETTLEABLE SOLIDS
SCREENINGS
MUD
PIT
GONDOLA SUPERNATANT
RETURN
SCREEN DISCHARGE
TO MUD PIT
SCREEN DISCHARGE
RESEVOIR
SUBMERSIBLE PUMP

Figure 1. Flow diagram of Phase I facilities.

TABLE 2. SOLIDS REMOVAL PERFORMANCE OF PHASE I FACILITIES

Date	Duration of Closed Mud Pit Run (8 hr shift)	Accumulated Mud Pit SS and Colloidal Solids (mg/l)	Accumulated Mud Pit SS and Colloidal Solids (lbs/shift)	Settleable Solids Removed by Teacup (ft^3/shift)	Settleable Solids Removed by Teacup (% solids)	Settleable Solids Removed by Teacup (lbs/shift)	Settleable Solids Removed by Teacup (%Total solids)	lbs/ton products
5/19/76 (Wed)	0.5	12,000	1,000	-	-	-	-	-
5/20/76 (Thurs)	1.5	23,000	640	150	74	12,745	95.2	84
5/21/76 (Fri)	2.5	30,000	500	150	74	12,745	96.2	83
5/22/76 (Sat)	0.5	1,200*	100	-	-	-	-	-
5/24/76 (Mon)	1.0	400*	17	-	-	-	-	-

* Fresh water was added to the cleaning operation.
All solids weight are expressed in dry weight.

The soil loading contributed to the wastewater varied daily depending on the amount of soil solids associated with the incoming product. As shown in Table 2, the accumulated suspended and colloidal solids per shift varied considerably, ranging from 17 to 1,000 lbs/shift. The portion of settleable solids removed by the teacup represented approximately 95% of the total solids contributed to the wastewater flow. The amount of total solids (dry weight) was about 83 lbs/ton of product, representing approximately 5% of the weight of the product processed.

The soil solids removal system effectively removed almost all the settleable solids from the system, which eliminated the discharge of the soil solids to the drainage ditch and the water free from the soil solids was reused for product transport and cleaning.

Phase II - Pilot Evaluation of the System for Suspended and Colloidal Solids Removal and Water Reuse

The objective of the Phase II pilot study was to determine the most cost effective means for producing water for high quality water reuse and for meeting the effluent requirement.

The pilot apparatus consisted of chemical feeding pump and diffuser, decayed gradient flocculator, gravity sedimentation tank, and granular media filter. The screen discharge water was coagulated by decayed gradient flocculator, settled in the gravity sedimentation tank, and finally polished by the filter. The summary of the pilot filtration performance is presented in Table 3.

Two sizes of filter media were investigated, one passing through 1.2 mm and retained by 0.8 mm openings, and another passing through 3.2 mm and retained by 1.6 mm openings. In filtering wastewater of high solids loading rate, it was found that the media size of 1.6/3.2 mm (retaining/passing) was more effective in producing high quality filtrate with a reasonably long filter run. It was also determined that the most effective mode of chemical addition was to inject the chemical coagulant immediately upstream of the filter media. The coagulation-flocculation and filtration of the colloidal solids occurred within the filter bed, eliminating the chance of surface cake formulation on top of the filter media. Therefore, excessive pressure drop across the filter media was eliminated.

The characteristics of the filtered wastewater varied, from recirculated wastewater to wastewater with fresh water added. The filtration rates tested ranged from 2.5 to 10 gpm/ft^2. The coagulant used was cationic polymer, trade name Cat-Floc (product of Calgon) and the chemical feeding rates varied, ranging from 20 to 100 mg/l. The influent turbidity ranged from 40 to 300 FTU (Formazin Turbidity Unit) and the filtrate turbidity ranged from 2 to 50 FTU. A significant reduction in turbidity was achieved. Therefore, with the proposed clarification and filtration system, the reclaimed water should be suitable for reuse as cull pit and/or mud pit make-up water.

TABLE 3. SUMMARY OF PILOT FILTRATION PERFORMANCE

Date	Filter Media (mm)	Filtration Rate (gpm/ft^2)	Wastewater Characteristics	Coagulant Conc. (Cat-Floc)		Filter Performance		Pressure Drop (ft. water)	Run Length (hr)	Reasons for Run Termination
				Coag.-Floc. -Sediment (mg/1)	Contact Filtration (mg/1)	Influent (FTU)a	Effluent (FTU)a			
5/21/76	0.8-1.2	5	2-3 day's recirculated water	100	50	170-210	10-28	37	1	deteriorated effluent quality and excessive pressure drop
5/22/76	0.8-1.2	5	fresh water added	0	50	150	17-24	32	1	deteriorated effluent quality and excessive pressure drop
5/22/76	0.8-1.2	2.5	fresh water added	0	50	290	2-10	41	2	excessive pressure drop
5/24/76	1.6-3.2	5 10.5 15	first day's recirculated water	20 20 20	0 0 0	42-58 70 52-90	9-15 9-20 20-50	0 0 16	2 1/2 1 1/2	deteriorated effluent quality

[a] Formazin Turbidity Unit

Phase III - Design, Installation, and Start-up of the Full Scale Solids Removal and Water Reuse System

Based on the results of the Phase II pilot studies, the full scale solids removal and water reuse system included:

1. Decayed gradient flocculator/gravity clarifier; and
2. Coarse media contact filter

The flow diagram of the complete system is shown in Figure 2. The portion of final polishing was designed to handle a continuous flow of 100 gpm of screen discharge wastewater. The layout of the proposed facility takes best advantage of the limited available space without infringing on traffic patterns.

The decayed gradient flocculator is a series of enclosed square channels coiled around the 6 foot diameter gravity clarifier. The size of the enclosed channels increases gradually downstream such that the most intensive chemical mixing occurs at the upstream at the point of chemical injection and the mixing intensity decreases as the floc travels downstream to enhance the flocculation. The flocculator/clarifier was elevated to gravity discharge the settled liquid slurry to haul equipment.

The contact filter was designed as a constant flow device, capable of accommodating a 10 foot pressure drop over the bed prior to backwashing. A novel backwash system allowed use of coarse filter media, thereby assuring effective solids removal with minimum buildup of pressure drop. Following the completion of each filtration cycle, the filter would be backwashed with transfer of filter solids to the flocculator/clarifier for final thickening and disposal.

The typical performance of flocculation/clarification and filtration system is presented in Table 4. The turbidity, SS, BOD, and COD of the screen discharge wastewater were 600 to 1,000 FTU, 1,200 to 5,300 mg/l, 20 to 55 mg/l, and 100 to 240 mg/l, respectively. In comparing the wastewater characteristics of the effluent from the flocculation/clarification with that of screen discharge, a significant reduction in all the parameters was noted. Further reduction of all the parameters was achieved by the filtration. The turbidity, SS, BOD, and COD of the effluent from the filter were 7 to 20 FTU, 10 to 30 mg/l, 5 to 10 mg/l, and 25 to 50 mg/l, respectively. The quality of the filtrate meets the discharge requirement and is suitable for reuse in the carrot processing operation.

SUMMARY

This plant, a direct discharger, installed a process water recycle and final effluent polishing system which produces a treated water quality commensurate with the plant's potable water. By taking the phased approach in developing an effective wastewater management program, the carrot processor obtained a performance guaranteed system. An approximate 35% savings in the total investment was realized relative to the comparable system.

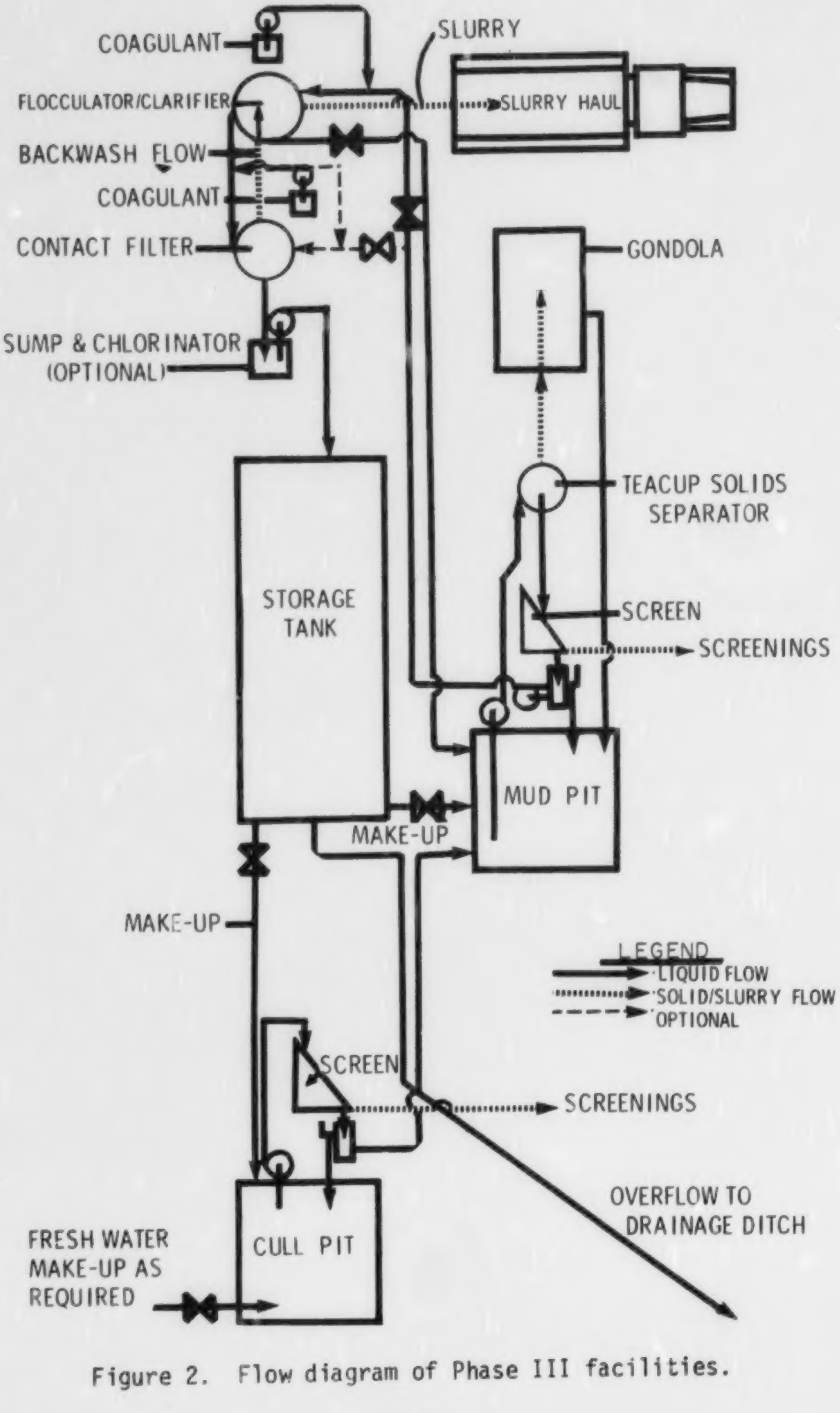
COAGULANT
SLURRY
FLOCCULATOR/CLARIFIER
SLURRY HAUL
BACKWASH FLOW
COAGULANT
CONTACT FILTER
GONDOLA
SUMP & CHLORINATOR (OPTIONAL)
TEACUP SOLIDS SEPARATOR
STORAGE TANK
SCREEN
SCREENINGS
MUD PIT
MAKE-UP
MAKE-UP
LEGEND
LIQUID FLOW
SOLID/SLURRY FLOW
OPTIONAL
SCREEN
SCREENINGS
OVERFLOW TO DRAINAGE DITCH
FRESH WATER MAKE-UP AS REQUIRED
CULL PIT

Figure 2. Flow diagram of Phase III facilities.

TABLE 4. TYPICAL PERFORMANCE OF FLOCCULATION/CLARIFICATION AND FILTRATION SYSTEM

Influent to Clarifier				Effluent from Clarifier (Influent to Filter)				Effluent from Filter			
Turbidity (FTU)	SS (mg/l)	BOD (mg/l)	COD (mg/l)	Turbidity (FTU)	SS (mg/l)	BOD (mg/l)	COD (mg/l)	Turbidity (FTU)	SS (mg/l)	BOD (mg/l)	COD (mg/l)
600-1,000	1,200-5,300	20-55	100-240	40-150	50-180	6-11	28-50	7-20	10-30	5-10	25-50

RECOVERY OF SOLUBLE SERUM PROTEINS FROM MEAT INDUSTRY WASTES

by

Richard W. Greiling*

INTRODUCTION

Wherever animals are slaughtered, decisions must be made on how best to dispose of the blood. For most meat and poultry packers the options are few. There was a time when the blood could be discharged into any receiving body of water along with other wastes. That time is gone. As effluent limitations became stricter, blood wastes in most abattoirs were retained for treatment with other renderable materials.

Blood is the largest single waste originating on the killing floor and, in terms of BOD, the strongest pollutant in the entire meat packing industry. Some studies suggest that 5-day biological oxygen demand (BOD_5) reductions of greater than 40 percent can be achieved by shifting from a no-recovery to a recovery of all blood wastes. In 1967, 80 percent of all packing plants in the United States were recovering blood. On a live-weight-kill (LWK) basis, 96 percent of the blood from slaughtered animals was recovered and treated in some form(1).

Standard sizes for blood recovery equipment are 5,000 lbs/hr (2,275 kg/hr) and 10,000 lbs/hr (4,550 kg/hr). Most recovery systems operate at a blood feed rate of 10,000 pounds per hour. In the most common blood recovery system blood is pumped through a steam-jacketed heat exchanger ranging in length from 10 to 20 feet (3 to 6 meters). To obtain a blood temperature of 90°C, at which rapid coagulation occurs, requires a blood retention time of 15 to 20 seconds, and 550 pounds (250 kg) of steam per hour. The blood clots are then centrifuged out of suspension for drying (spray drying is common) and packaging; the centrate being set to evaporation facilities or discharged to the sewerage system.

The biochemcial behavior of blood proteins in pure solutions has been understood for several years. The biochemical relationships, and influencing factors such as pH, ionic charge, temperature, and solids concentrations have been reported. What the literature fails to present is the biochemical behavior of blood proteins in a heterogeneous solution that has been subjected to the thermal and physical treatment mechanisms associated with blood recovery facilities.

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*Washington Department of Ecology, Olympia, Washington

DESIGN CONSIDERATIONS FOR PROTEIN RECOVERY

A minimum of constraints were placed on the development of a serum protein removal process. Aware of capital limitations that confront many abattoirs, certain factors concerning any final recommendation for a pre-treatment and recovery facility were of fundamental importance and necessitated constant consideration throughout the investigation.

First, the initial cost of facility construction must be low. Approximately 25 percent of the nation's slaughtering is done in small establishments(2)(3). A truly effective treatment scheme will be one that can be utilized by all meat packers. Low capital investment is a constraint on such a facility design.

Second, the process must be simple and relatively "foolproof". Operation should not require careful control or unpleasant tasks. Good treatment results should be visable to encourage the operator and convince him that his plant is really accomplishing its purpose.

Third, mechanical equipment should be held to a minimum to prevent shutdown due to failure and to cut maintenance costs. Duplicity of equipment should be avoided. Processes utilizing chemical and energy inputs should operate at the most optimum conditions to minimize operational costs.

OBJECTIVES OF THE INVESTIGATION

The literature suggests that increasing the temperature of a protein solution, particularly at its isoelectric point, enhances protein precipitation. Can the increased yield, however, justify the increase in thermal inputs? In a heterogeneous protein solution is there an optimum pH at which precipitation is most likely to occur? Is there a quantitative limit to protein recovery due to protein solubility relationships? And how close can a protein recovery system approach a limit of solubility and still be justified by economics?

The stimuli for effective blood recovery are a need for product recovery, and a determined need on the part of industry for effluent abatement. Perhaps the single most motivating force which will induce industry to consider further improved protein recovery is the energy costs associated with present recovery facilities. Most recovery systems are designed such that the liquid fraction of blood is mixed with other tank waters and dried by evaporation. Threatened unavailability of natural gas and fuel oil and rising energy costs associated with evaporators and driers are already forcing several abattoirs to change their rendering operations. One system improves centrifugation of blood particulates yet still discards the centrate to the sewer system(4).

What his facility fails to recover is the high quantity of dissolved serum proteins which represent a salable product.

Another objective of this research was to produce as pure and natural as possible a protein by-product which can be marketed. Fractionated proteins in a pure state yield the highest market price. However, facilities for such a treatment process are inaccessible to all but a few of the nation's meat packers. To meet the constraints previously discussed it became apparent that singularly or in combination heat, chemical, and physical methods may be necessary for protein extraction. The resultant protein solid is no longer in its natural state and losses the qualities necessary for pharmaceutical and highly specialized protein applications. It is cautioned, too, that the heat and pressure conditions found in an autoclave may make certain labile amino acids unavailable for nutriative purposes.

The markets of animal feed and fertilizer could be the receiver of such a controlled recovery product. Because of the pressing need for protein, it was hoped that a product could be recovered which can be marketed as an animal feed supplement. This objective is constrained because the Federal Food and Drug Administration does not allow the feeding of ruminants or other animals any feedstuffs chemically removed with synthetic polyelectrolytes(5). This constraint led to the investigation of the serum protein recovery capabilities of the organic polymer chitosin.

PRELIMINARY INVESTIGATIONS

Preliminary investigations were performed on a blood serum waste to asess the physical and chemical dependency of protein denaturation upon pH, temperature, protein concentration, and the presence of a coagulant aid. The intent of the investigations was to reduce the number of variables in question. A final design could be performed which would then provide data that could be used for the development of an operational protein recovery facility.

This blood serum waste stream, pH 6.7 to 6.9, has an organic nitrogen concentration of approximately 1,650 mg/l. Total solids are about 23,000 mg/l of which 15,000 mg/l are volatile. Assuming serum protein is 6.4 times the measured nitrogen assay at least 10,500 mg/l of the volatile solids fraction is attributable to serum proteins(6).

Variable Selection

The literature suggests that pH and temperature most strongly influence protein denaturation. Either variable alone can induce denaturation and coagulation, but no data have been reported on their combined influence on protein denaturation in a blood serum waste stream.

Protein denaturation occurs most rapidly at the isoelectric point of the solution. Consequently it was necessary to determine that pH point and then bracket it for subsequent analyses of protein recovery. The isoelectric point of the serum waste stream was to be determined by microelectrophoresis.

Denaturation is accelerated at elevated temperatures. Several temperature levels were used for preliminary investigations to determine the relation between temperature, protein solubility, and protein removal.

The literature suggests that protein stabilization against denaturation is inversely proportional to concentration. The effect of protein concentration on removal efficiencies was studied. In a recovery operation will the addition of wash-down waters sufficiently dilute the serum waste stream therefore hindering protein recovery?

Chitosin, an organic polymer composed of glucosamine residues, was used to help remove the suspended protein aggregates from solution. Chitosin has been shown to be an effective coagulant aid with protein-containing wastes(7). Approval for its use as a polymer for industrial applications and subsequent marketing in feedstuffs is pending before the Food and Drug Administration(5).

Determination of the Blood Serum Isoelectric Point

Protein mobility within an electric field was determined by measuring the time required for the aggregate to travel across a Howard counter microscope grid. Protein mobility is dependent upon the pH of the solution for the net ionic charge of the protein molecule changes with pH.

Microelectrophoresis was used to determine the isoelectric point of this heterogeneous solution. The sample was diluted with distilled water to make a 2.5 percent solution. Samples of the serum dilution were drawn and the pH randomly adjusted by using either 0.1 N KOH or 0.1 N HCl. The sample was then placed in the Briggs cell and a portion drawn thru the cell. Voltage was applied to the cell electrodes and the time of travel for a protein aggregate was recorded. After each set of observations, pH and specific resistance of the sample, and line current were recorded. For each pH the electrophoretic mobility was calculated.

The observed electrophoretic mobilities for a 2.5 percent serum solution are plotted against ph (fig. 1). The isoelectric point is where protein mobility is zero. For this 2.5 percent solution it occurs near pH 4.6 to pH 4.7.

Denatured Protein Settling Tests

Three settling tests were conducted to determine if denatured proteins would settle out of suspension. A stock solution of the serum waste and distilled water (for dilution) were heated to 60°C. Protein solutions were made up in serum : distilled water ratios of 1:0.25, 1:0.5, and 1:1. Each solution was adjusted to pH 4.6 and poured into a graduated cylinder.

Organic nitrogen and volatile solids tests were conducted on the supernatant in each column over a 24 hour period. All reported concentrations are adjusted for dilution. Solids concentrations were also determined on the settled solids at 24 hours.

A plot of residual organic nitrogen (fig. 2) suggests that blood serum protein removal by pH denaturation is independent of the concentration to at least a

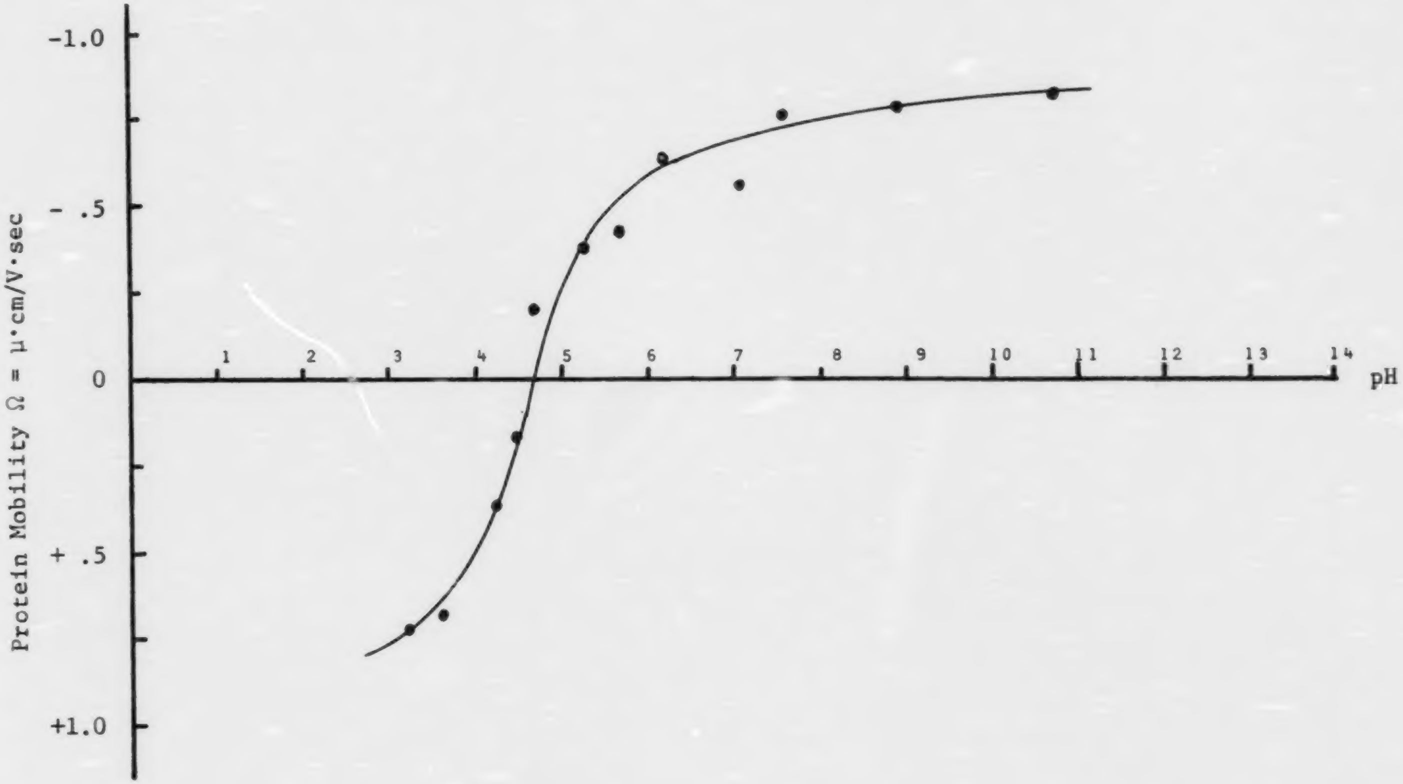

Figure 1. Electrophoretic Mobility of a 2.5 Percent Blood Serum Waste Stream as a Function of pH.

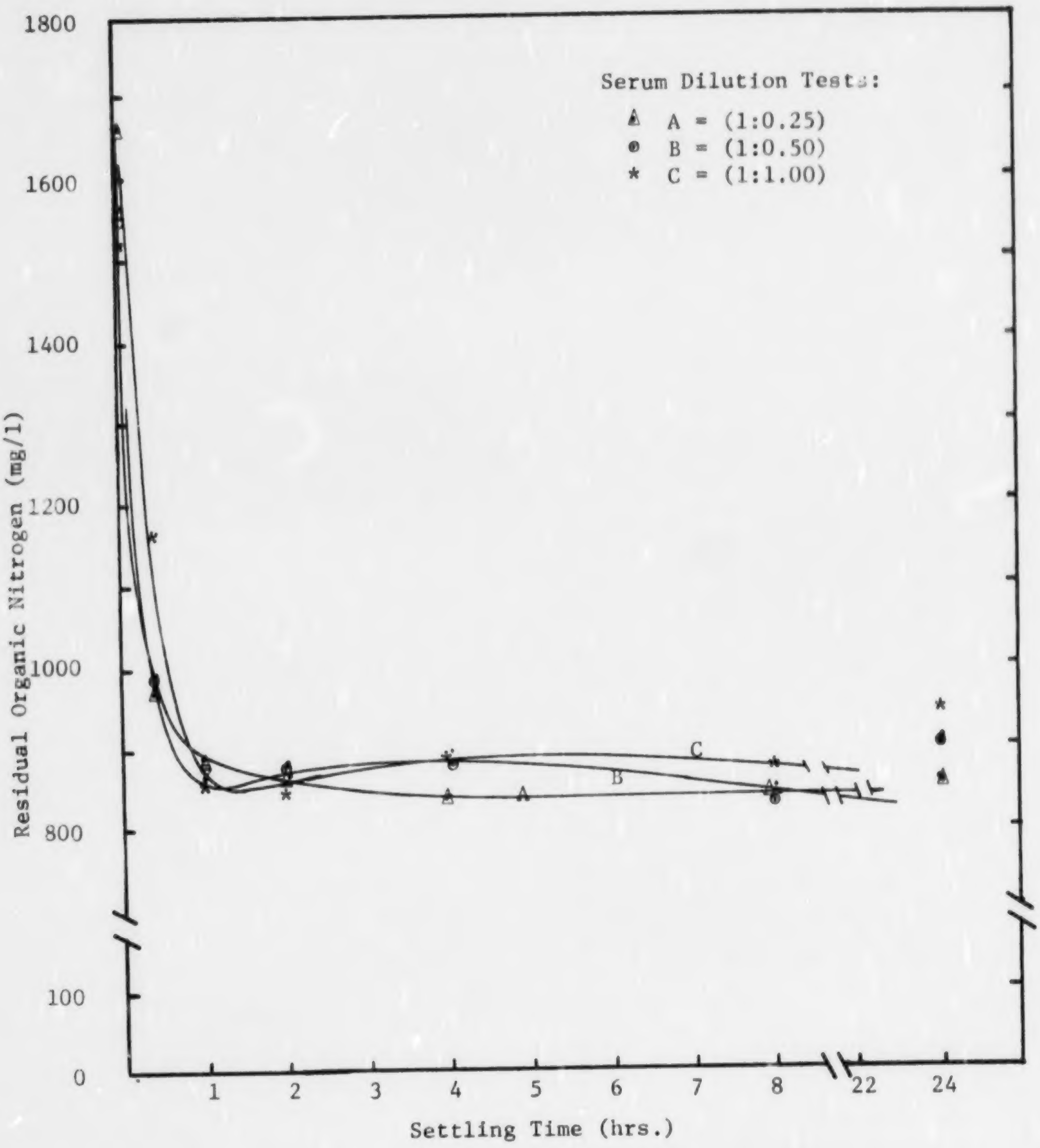

Figure 2. Organic Nitrogen Residuals for Three Serum Dilution Ratios at pH 4.6.

dilution of one. Within one hour all settleable solids have been removed from suspension.

At the end of 24 hours, a sample of the supernatant was centrifuged for five minutes at about 1,500-g. No additional removal of residual nitrogen concentration was observed. It was concluded that gravity settling for one hour will remove nearly all of the denatured protein aggregates. Centrifugation of the chemically treated serum waste stream would not be necessary to remove the denatured proteins.

At 24 hours, the settled solids are approximately 7 percent solids by weight and are 93 percent volatile. Visual examination of the graduated cylinders would suggest the settled solids to approximate 10 percent of the initial blood serum waste stream volume. The solids data indicate that few of the inorganic dissolved solids are being removed by either chemical complexation or entrainment in the protein aggregate. This suggests that dewatering of the settled solids could lead to a highly pure product with very little ash content.

Protein Recovery in a 2-Level Factorial Design

In an attempt to reduce the number of variables an investigation was conducted to determine the effect of pH, temperature, and protein concentration on recovery efficiency. The settling tests suggested that recovery was independent of concentration at low dilution. It was felt a factorial design would statistically varify that fact.

A 2^3 factorial design was developed. Temperature levels were $20^{\circ}C$ and $60^{\circ}C$. The lower temperature was selected for convenience and the higher temperature approximated the temperature of the serum waste stream of the centrifuge from which the samples were obtained. pH 4.6 was chosen for its proximity to the isoelectric point and pH 5.1 as a point in the range of high anionic mobility. Protein concentration levels selected were raw serum (dilution 1:0) and a 50 percent concentration (1:1).

Table 1 presents nitrogen and volatile solids concentrations and the observed standard errors for the design corner points. Standard errors for both nitrogen and solids concentrations are within the accuracy of the analytical procedures. To determine the significance of the main effects, an F-test with a 95 percent confidence level was conducted (table 2). At that level, $F_{(1,18)} = 4.41$.

Both organic nitrogen and volatile solids data suggest that the main effects of pH and temperature are statistically significant. The third level interaction is significant in nitrogen assays. The pH and temperature second level interaction and the third level interaction are significant in volatile solids data. Neither the main effect nor the second level interactions of protein concentration is significant. This lack of significance suggests the variable may be dismissed from subsequent investigations.

Both nitrogen and volatile solids results suggest that for the levels under investigation protein recovery is much greater near the isoelectric point

TABLE 1. ORGANIC NITROGEN AND VOLATILE SOLIDS CONCENTRATIONS FOR 2^3 FACTORIAL DESIGN

	NITROGEN RESIDUAL				VOLATILE SOLIDS RESIDUAL			
Test	No. Obsv.	Average mg/1	St. Error mg/1	%St.E.	No. Obsv.	Average mg/1	St. Error mg/1	%St. E.
Raw	3	1,570	40	2.5	3	12,500	350	2.8
1	3	1,070	46	4.3	3	9,560	510	5.3
2	4	907	52	5.7	4	8,390	510	6.1
3	3	1,200	12	1.0	3	10,400	120	1.1
4	3	985	54	5.5	3	9,050	250	2.8
5	4	1,210	53	4.4	4	10,700	170	1.6
6	3	777	29	3.7	3	7,200	310	4.3
7	3	1,280	26	2.0	3	10,900	110	1.0
8	3	1,200	60	5.0	3	10,500	330	3.1

$S_p^2 = 1,950$ St. Error = 44.1

$S_p^2 = 103,960$ St. Error = 322

	Analysis of Effects	Analysis of Effects
pH	-223	-1,610
T	+175	+1,250
D	+ 76	+ 475
pHxT	+ 75	+ 730
pHxD	- 34	- 345
TxD	+ 71	+ 500
pHxTxD	+101	+ 820

than at higher pH. Both tests suggest that a temperature of 60°C decreases the amount of protein recovered compared to that at 20°C. This result is opposite that expected. It may be hypothesized that protein solubility has increased with temperature and that the temperature selected was not high enough to induce thermal denaturation. Factorial design analysis suggested that thermal denaturation must occur above 60°C. This hypothesis is supported by later investigations.

The recovery of soluble proteins has again been shown to be independent of concentration up to a dilution of 50 percent. For this reason, the protein concentration was dismissed as an experimental variable. This conclusion suggests that small volumes of wash waters can be added to blood recovery operations without adverse effects to any subsequent protein recovery. From an operational viewpoint, volumes should be held to a minimum. Subsequent investigations were conducted using undiluted blood serum wastes.

TABLE 2. SUM OF SQUARES AND F-TEST FOR 2^3 FACTORIAL DESIGN

	ORGANIC NITROGEN			VOLATILE SOLIDS		
Effect	Sum of Squares	D.F.	F	Sum of Squares	D.F.	F
pH	49,729	1	25.50	2,576,025	1	24.78
T	30,625	1	15.70	1,562,500	1	15.03
D	5,776	1	2.96	225,625	1	2.17
pHxT	5,625	1	2.88	532,900	1	5.13
pHxD	1,156	1	0.59	119,025	1	1.14
TxD	5,041	1	2.59	250,000	1	2.40
pHxTxD	10,201	1	5.23	672,400	1	6.46
S_p^2	1,950			S_p^2 103,960		

$F_{(1,18)}^{0.025} = 4.41$

Establishment of the Polymer Dose

Investigations were conducted to determine the effectiveness of chitosin as a coagulant aid for the removal of suspended denatured proteins. Two investigations were conducted at 75°C and pH 4.65 and pH 5.4 Organic nitrogen and volatile solids analyses were performed on all samples. A subsequent investigation was conducted at 80°C and pH 4.65 to look at chitosin dosage levels and to determine any change in protein recovery due to a slightly higher temperature. Only organic nitrogen concentrations were measured.

Results for nitrogen concentrations plotted against chitosin dose (fig. 3) suggest that protein removal is enhanced with increasing polymer dosage up to

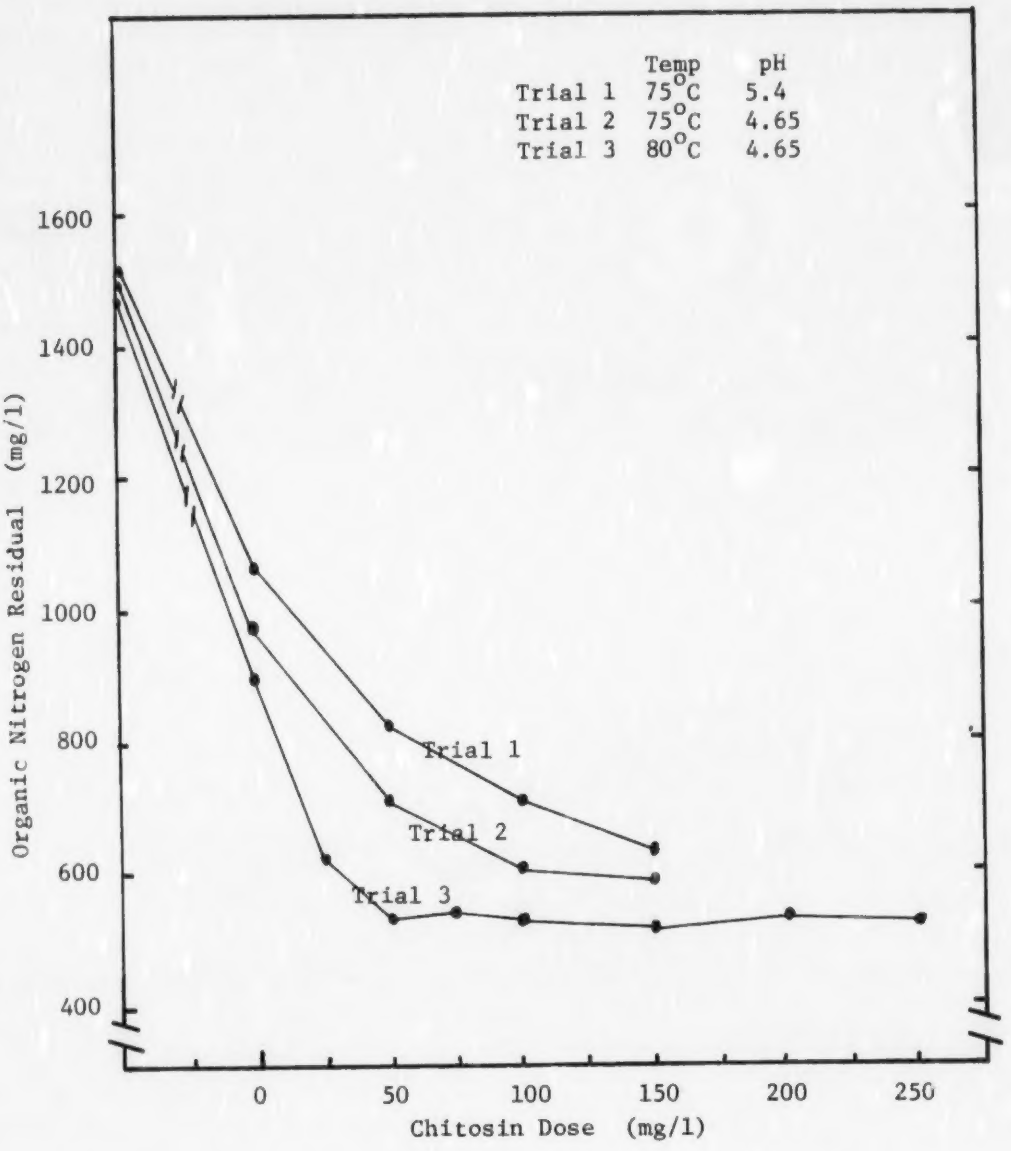

Figure 3. Organic Nitrogen Residual vs. Chitosin Dose.

a chitosin concentration of about 100 mg/l. Beyond that dosage there is a leveling off of the yield of protein recovered. The proteins remaining in solution appear no longer influenced by the presence of the chitosin.

In order to establish the range of pH values over which any final analyses should be performed, a series of investigations was conducted at 90°C. pH ranged from 5.8 to 3.8 at intervals of 0.4 pH units.

Figure 4 suggests that protein recovery is strongly influenced by both pH and chitosin dose. Two significant observations may be noted. First, at low chitosin concentrations, the maximum recovery of proteins occurs well below the isoelectric point of the protein solution; protein yield is greatest at pH 3.8. Second, at a chitosin concentration of 100 mg/l protein recovery is maximized over a range of pH 5.0 to pH 3.8. The recovery has been maximized for the given variables and that the residual protein concentration is most likely limited by protein solubility.

EXPERIMENTAL DESIGN AND CONCLUDING INVESTIGATIONS

Selection of Design Variable Levels

It has been determined that a minimum temperature of about 60°C is required for thermal denaturation of proteins. Theoretically, thermal denaturation of all proteins occurs at 100°C. The variable levels for temperature were thus limited by these two temperatures. Complications arise with operating temperatures near the boiling point of the serum solution. Excessive steam would create operating problems. Heat inputs would be nearly as great as present evaporation facilities. As such, a maximum operating temperature of 90°C was hypothesized. Temperature levels to be investigated were 60°C, 75°C, and 90°C.

Preliminary investigations suggest that protein recovery is greatly improved with polymer doses of 20 to 100 mg/l. Chitosin doses of 20, 60, and 100 mg/l were used in the final design.

A strong interaction between pH and chitosin dose suggest that a wide pH range can yield maximum protein recovery. Preliminary investigations suggest this pH range to be from pH 5.0 to at least pH 3.8. In an attempt to fully bracket the pH range, final investigations were conducted from pH 5.4 to pH 3.4. Six levels 0.4 pH units apart were selected for observation.

Procedure

The final design is a matrix with variable levels of 3 x 3 x 6. The design was to be run in duplicate, with any remaining serum samples being used to triplicate the experiment. The order in which samples were run was only partially randomized. Because of equipment restraints, only one temperature level could be conducted at a time. Both pH and polymer dose levels were randomized for a particular temperature level.

A large serum sample was heated to the desired temperature. A 300 ml sample was withdrawn and pH adjusted at random. A 100 ml sample was then added to

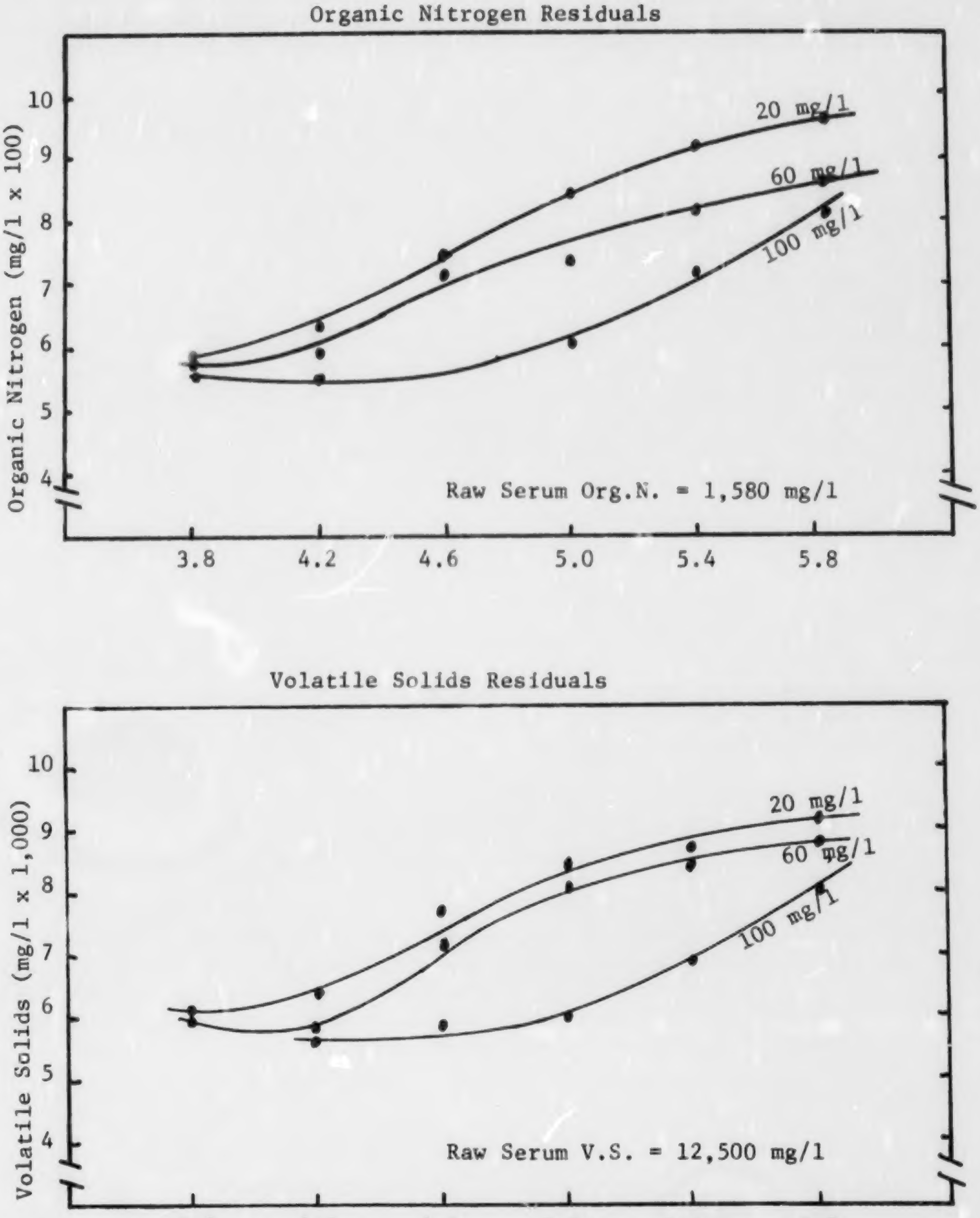

FIGURE 4. **Residual Organic** Nitrogen and Volatile Solids Concentrations as a Function of pH and Chitosin Dose at 90°C.

each of three bottles containing the amount of chitosin to yield the desired polymer concentration. The bottle was stoppered and placed in the warm air oven for a reaction and settling time of one hour. After clarification the supernatant was tested for organic nitrogen and volatile solids.

A total of 134 tests was conducted. This provides for triplication of about one half of the design matrix. All other test conditions were duplicated.

Results

Protein recovery was determined as percent of nitrogen or volatile solids removed from solution and suspension. Protein recovery efficiency varies from 31 to 62 percent. Efficiencies are slightly higher for organic nitrogen assays than for volatile solids. Earlier mass balance approximations suggested that proteins accounted for about 70 percent of measured volatile solids. The solubility of dissolved salts will limit the efficiency of volatile solids removal. This limitation will tend to depress the percent reduction of volatile solids independent of the reduction of dissolved organic nitrogen.

Regression Analysis of Protein Recovery Efficiencies

Isometric projections of protein recovery efficiencies (as measured by organic nitrogen) were drawn to assist data interpretation (figs. 5-7). The projections suggest recovery is highly dependent upon pH and polymer dose and nearly independent of temperature.

Recovery is most effective in the range of pH 3.8 to pH 4.6. Within that range recovery is nearly independent of the chitosin dose. At pH values above 4.6 the recovery is highly dependent upon polymer dose. Both of these observations confirm earlier investigations into the effectiveness of pH as a denaturant and chitosin as a coagulant aid. That recovery efficiencies do not significantly improve with increasing temperatures is contrary to earlier hypotheses. Protein solubility in the high dissolved salt solution must be limiting protein recovery efficiencies.

To facilitate ease in using experimental results an attempt was made to develop a model which would predict protein recovery efficiency as a function of pH, temperature, and chitosin dose. Isometric projections of organic nitrogen removal efficiencies suggest a second order response to both pH and dose. A linear response to temperature is suggested by the three projections.

Several models were used in a multiple regression analysis. The model was to fit an equation through the 54 data points collected in the test matrix. The parameters $(T)^2$ and (T x Dose) were insignificant. A six-parameter model (linear in the parameters) for predicting the removal efficiency for organic nitrogen is:

$$F = 0.54(T) + 52.0(pH)^2 - 6.56(pH)^2 - 0.44(Dose) - 0.09(pH \times T)$$
$$+ 0.12(pH \times Dose) - 59.87$$

where F is organic nitrogen removal efficiency as percent (see table 3).

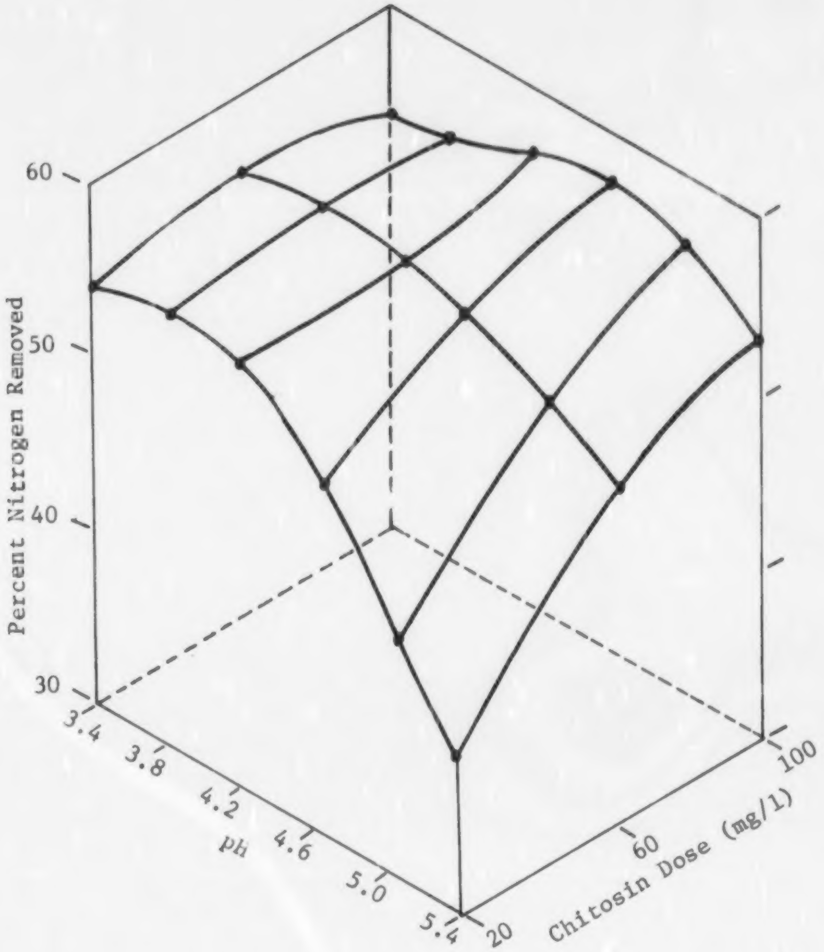

Figure 5. Organic Nitrogen Removal Efficiencies as a Function of pH and Chitosin Dose at 60°C.

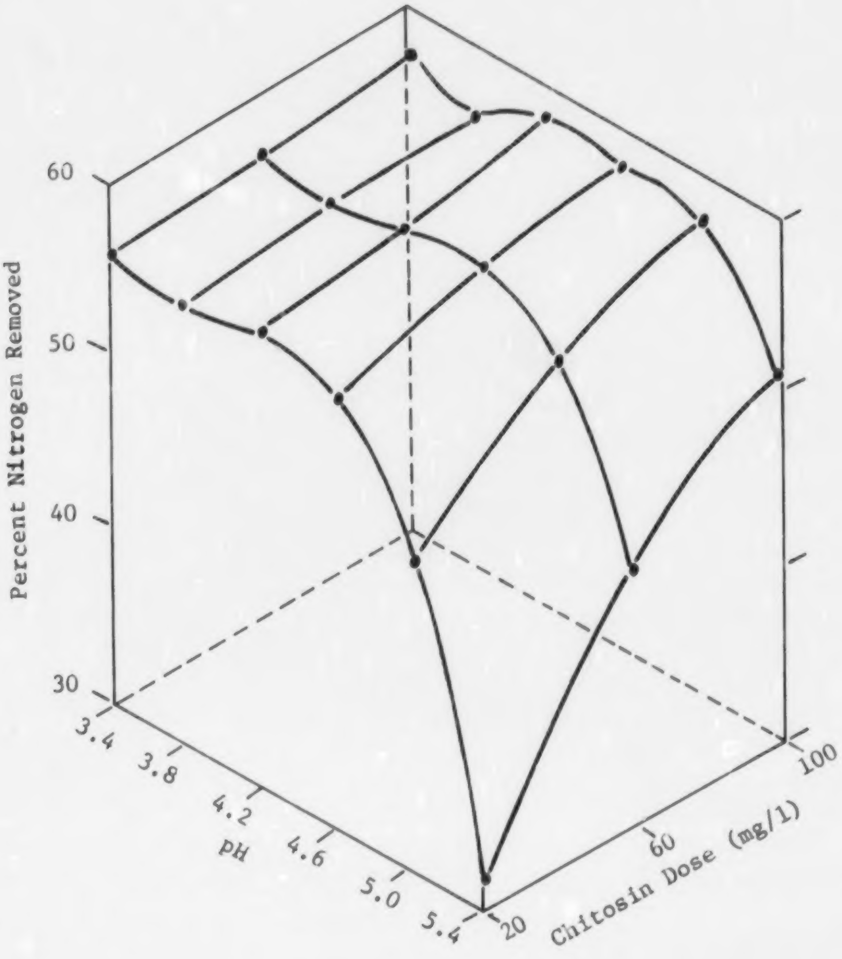

Figure 6. Organic Nitrogen Removal Efficiencies as a Function of pH and Chitosin Dose at 75°C.

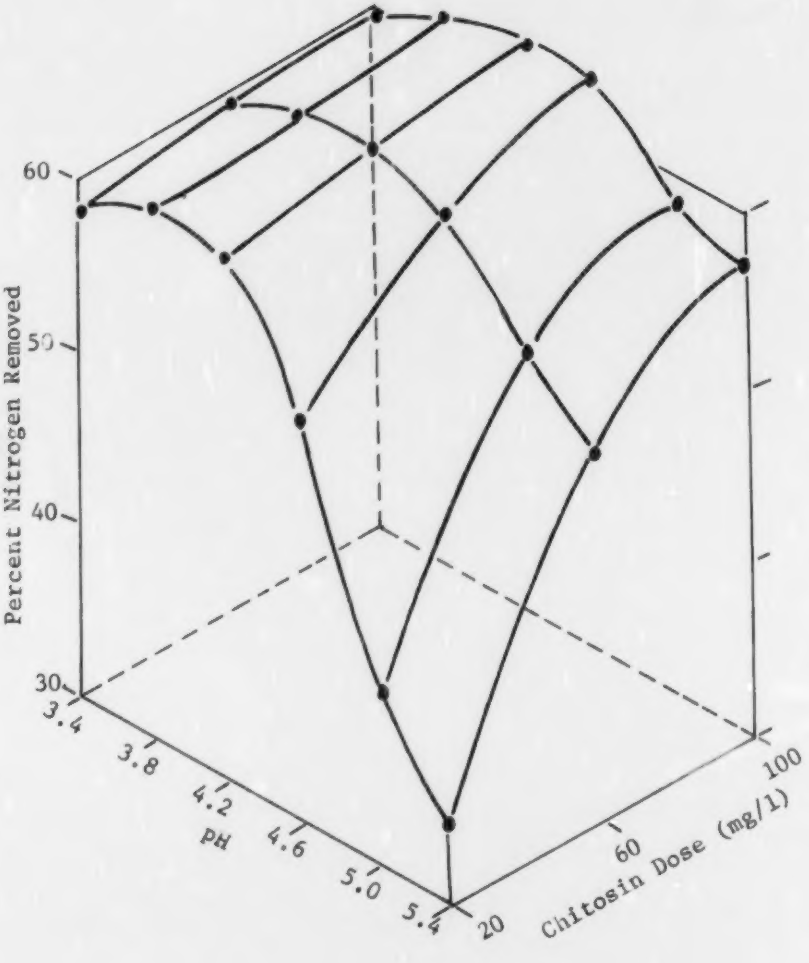

Figure 7. Organic Nitrogen Removal Efficiencies as a Function of pH and Chitosin Dose at 90°C.

$$F = \Theta_2(T) + \Theta_3(pH) + \Theta_4(pH)^2 + \Theta_5(Dose) + \Theta_6(pH \times T) + \Theta_7(pH \times Dose) + \Theta_0$$

Variable No.	Mean	Standard Deviation	Correlation X vs Y	Regression Coefficient	Std. Error of Reg.Coef.	Computed T Value
2	7.5000E+01	1.2363E+01	2.5340E-01	5.3847E-01	1.7002E-01	3.1670E+00
3	4.4000E+00	6.8954E-01	-5.6012E-01	5.1984E+01	7.6656E+00	6.7815E+00
4	1.9827E+01	6.0814E+00	-5.8526E-01	-6.5528E-01	8.0027E-01	-8.1883E+00
5	6.0000E+01	3.2967E+01	4.1808E-01	-4.4068E-01	6.3758E-02	-6.9117E+00
6	3.3000E+02	7.5529E+01	-2.1404E-01	-9.1489E-02	3.8184E-02	-2.3960E+00
7	2.6400E+02	1.5251E+02	3.0550E-01	1.1927E-01	1.4319E-02	8.3293E+00
Dependent						
1	5.4172E+01	6.6312E+00				

Intercept	-5.98778E+01
Multiple Correlation	9.42796E-01
Std. Error of Estimate	2.34752E+00

Analysis of Variance for the Regressi[illegible]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F Value
Attributable to Regression	6	2.07156E+03	3.45260E+02	6.26510E+01
Deviation from Regression	47	2.59010E+02	5.51085E+00	
Total	53	2.33057E+03		

TABLE 3. REGRESSION ANALYSIS FOR ORGANIC NITROGEN REMOVAL EFFICIENCY

The correlation between the variables and the removal estimates are intuitively satisfying. There is a small, but significant, positive correlation with temperature. The greatest correlations for the model related estimated protein recovery with pH. For the pH range under study, the lower the pH the greater the recovery. There is a fairly large positive correlation between chitosin dose and product recovery for both chitosin in the first order and its interaction with pH.

Dissolved Protein Removal by Carbon Adsorption

A laboratory investigation was conducted to determine if dissolved protein removal, beyond that recovered by denaturation and polymer coagulation, could be achieved with activated carbon. The extension of carbon capacity may be very significant under certain conditions. Decreasing pH and increasing temperatures increases the adsorptive characteristics of activated carbon. These two conditions are attained in the chemically treated blood serum waste, and the high dissolved organic content should enhance surface adsorption.

A preserved serum waste was heated to 60°C, pH adjusted to 4.6, and mixed with chitosin at a dose of 100 mg/l. After one hour of settling the supernatant was withdrawn and 300 ml samples were added to six test vessels containing measured amounts of powdered carbon. The stirrer and carbon suspensions were maintained at 60°C in a heated room. Carbon suspensions were stirred at 40 rpm for a two hour activated carbon residence time. A five minute centrifugation at about 3,600-g provided excellant solid/liquid separation.

Organic nitrogen, chemical oxygen demand (COD), and volatile solids analyses were conducted on the raw serum waste, the waste chemically treated for protein recovery, and on the six carbon adsorption centrates (table 4). Analyses were conducted to determine carbon adsorption capacities for protein removal.

The adsorptive capacity for the powdered carbon was determined by comparing the amount of COD removed per unit of carbon versus the COD loading rate. The total COD used in the adsorptive capacity test was determined by measuring carbonaceous COD and adding to that the theoretical oxygen demand of the organic nitrogen concentration.

When the adsorptive capacity of the activated carbon is plotted against residual COD (fig. 8), the curve shows that carbon adsorption removal improves with increasing concentration of dissolved organics. It is noted here, too, that as the concentrations of dissolved organics increase, the rate of unit increase in adsorptive capacities is less that unity.

That protein removal by activated carbon is significant leads to the development of unit processes beyond protein recovery. Spent granulated carbon from removal operations involving low organic concentrations may yet have sufficient adsorptive capacity to polish the organic-rich supernatant. Following protein recovery by denaturation and coagulation, the supernatant

Sample	Carbon Dose g/1	COD mg/1	Org. N mg/1	Total COD[b] mg/1	T.S. mg/1	V.S. mg/1	$\frac{\text{mg COD}_l}{\text{mg Carbon}}$[c]	$\frac{\text{mg COD}_r}{\text{mg Carbon}}$
Raw Serum	---	12,400	1,760	20,400	23,800	16,200	----	----
Treated[a] Serum	---	7,780	680	10,900	8,420	3,990	----	----
1	4	7,080	407	8,940	8,630	3,560	2.73	0.49
2	8	5,860	274	7,720	7,770	2,680	1.36	0.40
3	20	3,150	209	4,110	7,160	2,040	0.55	0.34
4	40	2,300	149	2,980	6,670	1,530	0.27	0.20
5	80	1,090	71	1,410	6,570	1,150	0.14	0.12
6	160	804	52	1,040	7,130	1,080	0.07	0.06

a. pH = 4.6; T = 60°C; Chitosin = 100 mg/1
b. Total COD = Carbonaceous COD + 4.57(Org. N concentration)
c. mg $\text{COD}_{\text{loading}}$/mg Carbon = 10,900 mg COD/(X mg Carbon)

TABLE 4. CARBON ADSORPTION COD REMOVAL

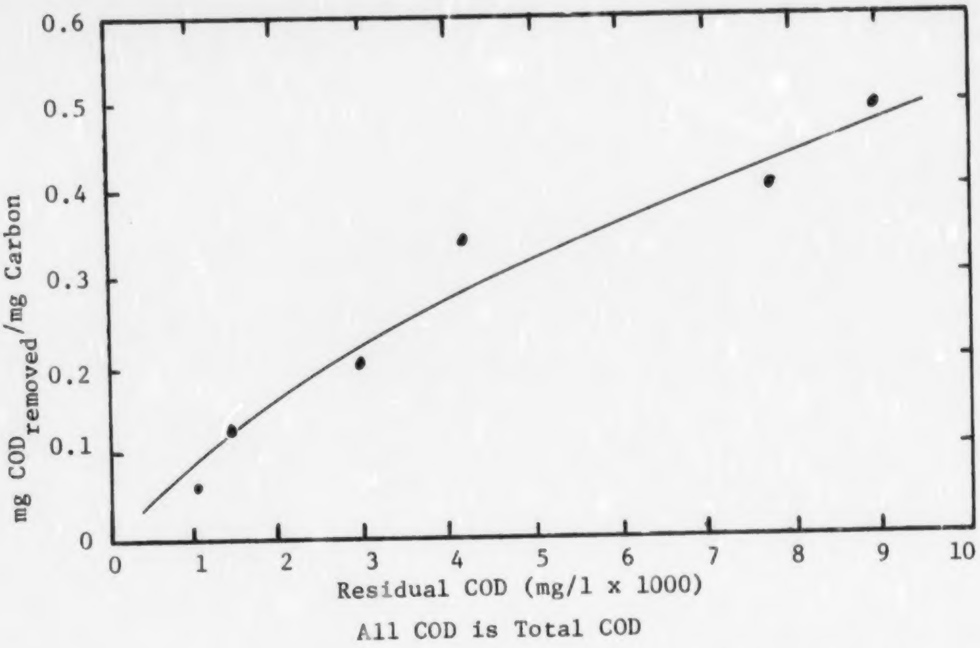

Figure 8. Adsorption Capacity vs. Residual COD.

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would pass through a granulated carbon adsorption unit prior to disposal. Sorbed proteins would be wasted.

Once the optimum loading rate has been determined, powdered activated carbon may be added to the treated serum supernatant. When slaughtering has ceased the slurry could be returned to the centrifuge at the head of the blood recovery operation. The centrate would be discharged to the sewerage system. Depending on the market for recovered proteins and the ash content of the activated carbon solids, the solids removed during centrifugation would either be mixed with the blood cell and recovered protein solids or wasted.

Estimated Costs for Recovery of Soluble Serum Proteins

A recovery system for which costs are estimated chemically treats the serum waste stream from a blood centrifuge. Following pH and thermal denaturation and protein coagulation, the settled solids are evaporated and marketed and the supernatant is wasted.

Chemical addition can be either continuous feed or batch feed. Concentrated acid should not be added directly to the serum due to localized severe protein structural deformation and also because of the hazards associated with working with strong acids. Thus both pH and polymer mixing tanks and feed systems will be required. Some heat exchange unit (steam jacket around the tank) will be necessary to maintain elevated temperatures sufficient to induce thermal denaturation. The tank can be covered to minimize the release of odors and loss of heat.

Cost estimates assume a large slaughterhouse kills 5,000 hogs per day and each hog loses one gallon (3.7 liters) of whole blood(8). Following centrifugation of coagulated blood cells, the serum is sent to a 1,000 cubic foot (29 cubic meter) holding tank. Temperature is maintained between 60°C and 70°C. After slaughtering is complete, the serum temperature is raised to 70°C, pH adjusted to 4.2, and chitosin added to enhance coagulation. After a reaction and settling time of four hours (as determined by particle settling velocity) settled proteins are withdrawn for evaporation and the supernatant is wasted. The tank and lines are cleaned, wash waters being sent to the sewer.

Because of corrosive acidic conditions, the entire system is made of stainless steel. Both pH and chitosin solutions are made once a week. The small daily requirements make this possible. Chemical treatment is done on a batch basis at the end of the work day. The operator reads the level of serum in the settling tank and manually adjust the polymer feed for the desired dosage. pH is monitored and is either manually or automatically adjusted. Valves are located in several lines to direct waste and product stream flows.

A cost estimate for the capital investment suggests this design to cost approximately $17,000. Operation costs (excluding labor) for the heat exchange unit, evaporation unit, and chemical precipitation have been generated for cost comparison purposes. Conventional evaporation costs were computed on a daily loading rate of 5,000 gallons (18,700 liters) of serum. Capital investment was amortized over ten years (at 10 percent) and daily costs established on the basis of 250 work days per year.

Table 5 shows operational costs and benefits associated with the protein recovery system. Total operating expenses (excluding labor and carbon adsorption) are about $41 per day. Recoverd proteins have a value of $34 per day. When cost savings associated with present evaporation systems ($140/day) are added to the value of the protein by-product, a net savings in treatment costs results with the protein recovery system. These savings could be used to polish the chemically treated serum supernatant in an activated carbon unit. This would reduce the organic load to the sewer system.

Simplicity of design affords the use of this system in all industries that require treatment of blood wastes. Energy needed to evaporate blood water is the greatest cost associated with present blood recovery operations. By precipitating dissolved proteins and reducing blood waste volume by 90 percent, costs of evaporation are greatly reduced. That savings, plus the marketing of a protein by-product, can most probably cover the costs of the recovery system for both a small and large slaughtering operation.

TABLE 5. PROTEIN RECOVERY OPERATION COSTS AND SAVINGS
(5,000 gpd Raw Serum)

Chemical Supplies	
Chitosin (0.8 lbs/day @ \$5/lb)	= \$ 4.00
Acid (6.5ℓ conc. H_2SO_4 @ 90¢/ℓ)	= 5.80
Steam	
Heat Exchanger (3,200 lbs/day @ \$3.50/1000 lbs)	= 11.20
Evaporation (3,400 lbs/day)	= 11.90
Capital Recovery (10 years, 10 percent)	
\$16,670 x 0.06275 = \$1,050/yr	
\$1,050/250 work days	= 4.20
Neutralization and Treatment of Supernatant (\$1/1000 gals)	= 4.50
Total Daily Cost	= \$ 41.60
Salable Protein Feedstuffs	
340 lbs/day @ 10¢/lb	= \$ 34.00
Steam Savings from present Evaporation Facilities	
(39,050 lbs/day @ \$3.50/1000 lbs)	= 136.70
Total Daily Savings	= \$170.70
Total Savings - Total Costs	= \$ 130.00 per day

CONCLUSIONS

Laboratory investigations reveal that dissolved serum proteins may be recovered economically by ph and temperature denaturation. The organic polymer chitosin is an effective coagulant aid. Laboratory investigations suggest:

1. Dissolved serum proteins can be removed most effectively when the pH of the solution is at or below the isoelectric point of the solution.
2. Protein recovery is enhanced by thermal denaturation. A minimum operating temperature of 60°C should be maintained for maximum recovery.
3. In the pH range of 3.4 to 5.4 and in the presence of the polymer chitosin, protein removal efficiency is nearly independent of temperatures above 60°C.

4. Both organic nitrogen and volatile solids tests suggest protein removal to be approximately 60 percent efficient. Both analytical procedures yield similar efficiencies for given variable levels.

5. Protein removal efficiency as measured by organic nitrogen can be predicted with a six parameter model. Removal efficiency is more dependent upon pH and polymer dose than on temperature.

6. Denatured protein aggregates are sufficiently large to settle out of suspension be gravity. The volume of settled solids is about 10 percent of the volume of the original waste stream.

7. Settled protein solids approximate 7 percent solids by weight. Over 90 percent volatile, the solids can be withdrawn, dried, and marketed as a protein-rich feed supplement.

8. The supernatant from chemical treatment of the serum waste stream can be polished further by using activated carbon to adsorb dissolved organics. COD reductions of 90 percent can be accomplished when the serum waste stream is treated to recovery dissolved proteins and then treated with activated carbon.

9. Dissolved salts in the serum waste stream are not significantly reduced by either chemical protein coagulation or activated carbon.

10. The high dissolved salt concentrations may tend to limit protein recovery because of protein solubility in saline solutions.

11. Because daily operating costs are low, protein recovery from blood wastes should be an attractive alternative to present blood recovery techniques. The estimated net worth of the dried protein product plus cost savings from present treatment systems should be more than sufficient to amortize the required capital investment and also cover preliminary cost estimates.

12. Chemical treatment for the recovery of serum proteins appears even more attractive in light of the fact that rising energy costs are making evaporation operations prohibitively expensive.

REFERENCES

1. Jones, H.R. Pollution Control in Meat, Poultry, and Seafood Processing. Noyes Data Corporation, Park Ridge, New Jersey (1974).

2. Steffen, A.J. "Waste Disposal in the Meat Industry: A Comprehensive Review". Proc. of the Meat Industry Research Conference, American Meat Institute Foundation, Chicago, Illinois, pp 115-144 (March, 1969).

3. Stiemke, R.E. "Disposal of Wastes from Small Abattoirs". Proc. of the 4th Industrial Waste Conference, Purdue University, West Lafeyette, Indiana, pp 178-202 (1948).

4. Anonymous. "Blood System Solves Processing Problem". Reprint from Meat Processing, April (1971).

5. Bough, W., Landes, D., Miller, J., Young, C., and McWhorter, T. "Utilization of Chitosin for Recovery of Coagulated By-Products from Food Processing Wastes and Treatment Systems". Reprint from the Department of Food Sciences, Univ. of Georgia College of Agriculture Experiment Station, Experiment, Georgia (1975).

6. Watson, D. "Factors for Calculating Serum Albumin and Total Protein from the Nitrogen Conten". Clinica Chimica ACTA, 16:322-333 (1967).

7. Bough, W. Personal Communication (1975, 1977)

8. Ullmann, J.E., editor. Waste Disposal Problems in Selected Industries. Hofstra University Yearbook of Business, Series 6, Vol. 1. Hofstra University (1969).

IMPROVED BIOLOGICAL TREATMENT OF FOOD PROCESSING WASTES WITH TWO-STAGE ABF PROCESS

by

B. W. Hemphill* and R. G. Dunnahoe*

INTRODUCTION

Biological treatment of food processing and combined food processing/municipal wastes has historically presented unique problems because of: 1) highly erratic flows and wastewater strengths; 2) high soluble organic concentrations; and 3) tendencies to contribute to operational problems such as bulking of activated sludge due to the presence of high levels of carbohydrate materials (1). Traditional fixed-film treatment systems such as trickling filters have often been used on these wastes because of their relative stability under changing loads and low operating costs (2)(3). However, they are limited because of high land area requirements, high capital costs, and inferior effluent qualities. Suspended growth systems (activated sludge) have been used because of their lower first cost, higher effluent quality, and lower land requirements. The success of these systems has been hindered by their operational complexity, their sensitivity to shock loadings and tendency to be unstable under conditions such as those typically imposed by food processing plants.

The activated bio-filtration (ABF) process has been developed to make use of the advantages of both the fixed-film and suspended growth treatment systems while minimizing the disadvantages. A superior process stability is realized over a wide range of wastewater characteristics and treatment problems. This paper will summarize the development of the ABF process in treatment of food-processing waste and will present operating data from both pilot scale studies and full-scale plants.

ABF PROCESS DESCRIPTION

Figure 1 shows the flow schematic for the ABF process. After primary treatment, the wastewater is combined with return sludge from the secondary clarifier and Bio-Cell recycle to form a mixed liquor which is then pumped to the Bio-Cell. The Bio-Cell reactor contains horizontal bio-media, to which fixed-film organisms attach. The suspended growth organisms combine with the fixed-film to oxidize the biodegradable organics. The Bio-Cell underflow is split, with a portion being returned as Bio-Cell recycle and the remainder proceeding to a short-term aeration basin. The aeration basin acts as a complete mix activated sludge basin, which further oxidizes organic materials and provides a flocculent mixed liquor prior to final sedimentation. Settled biological solids are recycled to the Bio-Cell lift station with a portion going to waste. For roughing applications, the aeration basin is often deleted from the flow scheme.

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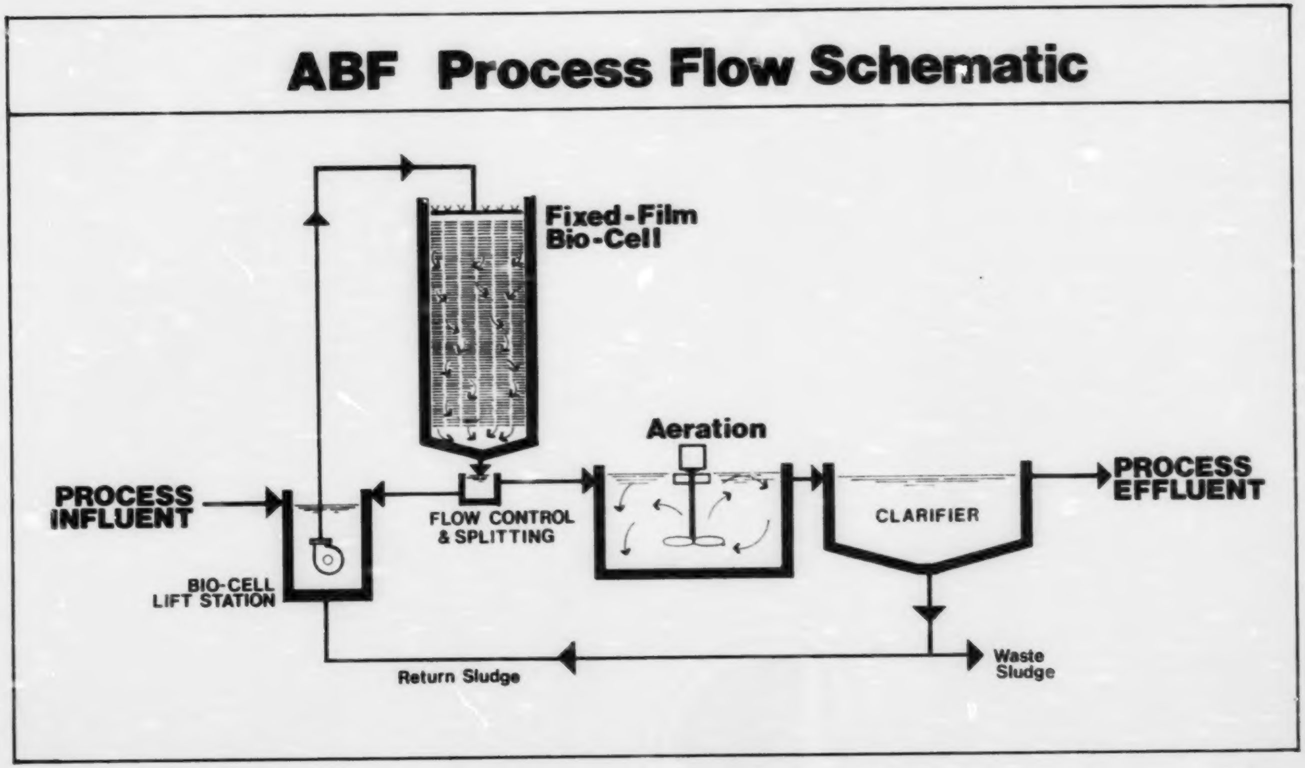

ABF Process Flow Schematic
Fixed-Film Bio-Cell
Aeration
PROCESS INFLUENT
BIO-CELL LIFT STATION
FLOW CONTROL & SPLITTING
CLARIFIER
PROCESS EFFLUENT
Waste Sludge
Return Sludge

Figure 1.

The horizontal ABF bio-media consists of individual racks made of wooden lath fixed to supporting rails, as shown in Figure 2. The horizontal configuration of the media provides turbulent conditions, which are necessary to maintain a high dissolved oxygen environment and particle-micro-organism contact. Oxygen transfer is provided by the dual action of wastewater continually moving in a film across the biota, and splashing between layers. The open design permits free flow of air in all directions, and prevents ponding or bridging.

Sludge Recycle

One of the keys to the operation of the ABF process lies in the application of biological solids to the fixed-film Bio-Cell. Numerous studies have verified the advantages of this. These include studies at Corvallis, Oregon (4), Turlock, California (5)(6), and Tracy, California (7).

At Corvallis, direct comparisons were made between identical fixed-film Bio-Cells, with one unit utilizing sludge recycle (ABF), run next to a unit operated as a conventional high-rate trickling filter (HRTF). Horizontal media were used in both systems. The wastewater consisted of domestic and combined beet processing/domestic waste. Comparative data for the two systems are shown in Figure 3. The soluble removal efficiency for the ABF tower was approximately twice as great as for the HRTF tower. Similar measurements were taken when the Bio-Cells were followed by high rate activated sludge systems. Further evidence of the increased Bio-Cell removal in the ABF mode was found in the measurement of the aeration basin oxygen uptake rate (OUR) for the two systems. The OUR of the ABF system was approximately 50% less than that of the parallel HRTF-activated sludge system.

Similar tests were made at Tracy, California (7), where side-by-side studies were run of ABF-activated sludge and HRTF-activated sludge systems. Measurements taken during the study indicated a significantly greater soluble COD reduction across the Bio-Cell with the application of return sludge.

An additional process benefit that has been associated with recycling of sludge to the fixed-film unit is that of increased process stability. This was demonstrated in the Tracy, California (7), and Turlock, California (5)(6), pilot studies. Both studies were run on combined food processing and domestic wastes. Both included side-by-side comparisons of the ABF process with horizontal media and the HRTF-activated sludge process with vertical media. At Turlock, mechanical problems early in the study caused a period of dissolved oxygen deficiency in both systems, resulting in development of filamentous organisms. After the problem was corrected, the ABF system recovered readily, reaching full treatment efficiency in 7 to 10 days. However, the HRTF-activated sludge mixed liquor settleability did not improve as did the ABF mixed liquor. Throughout the study, the HRTF system continued to have problems with solids settleability and carryover of solids into the final effluent. The HRTF-activated sludge system did not meet the discharge requirements of 30 mg/1 BOD and TSS during the test periods with yam canning contributions, while the ABF system averaged 16 mg/1 BOD and 11 mg/1 TSS. Similar results for both systems were observed at Tracy.

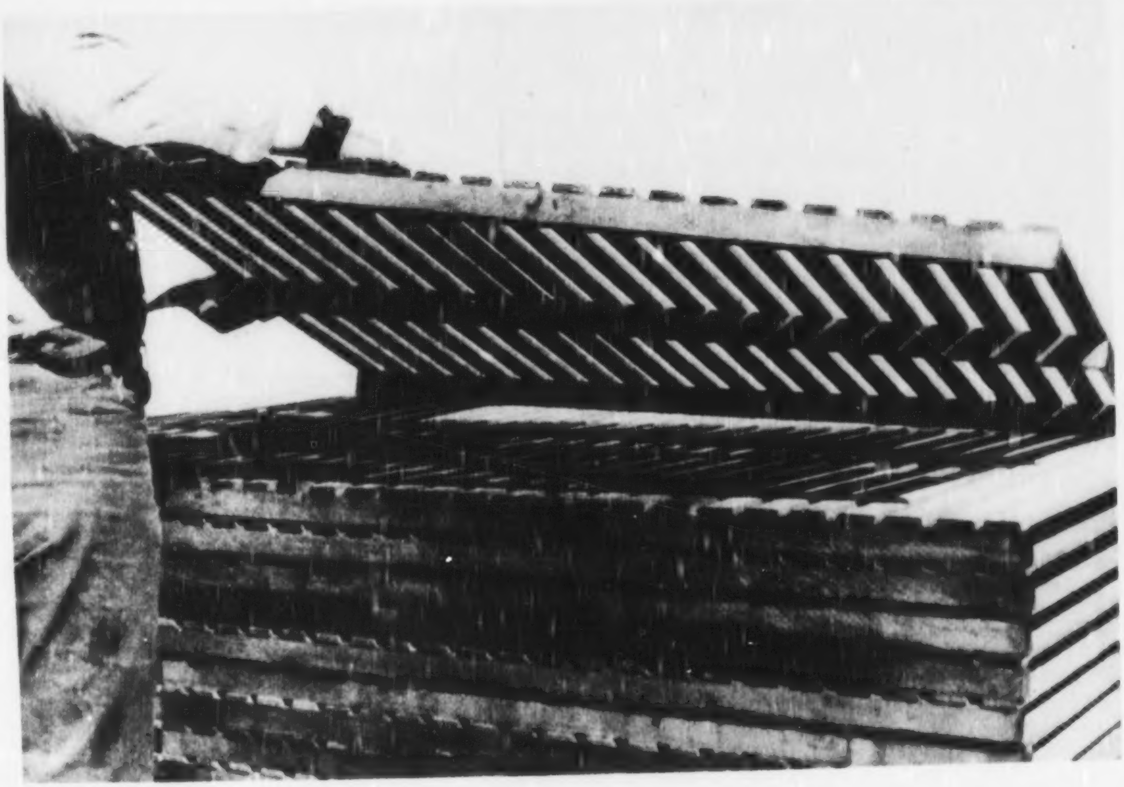


Figure 2. Horizontal media.

Comparison of Soluble Organic Removal ABF (Without Aeration) & HRTF Processes

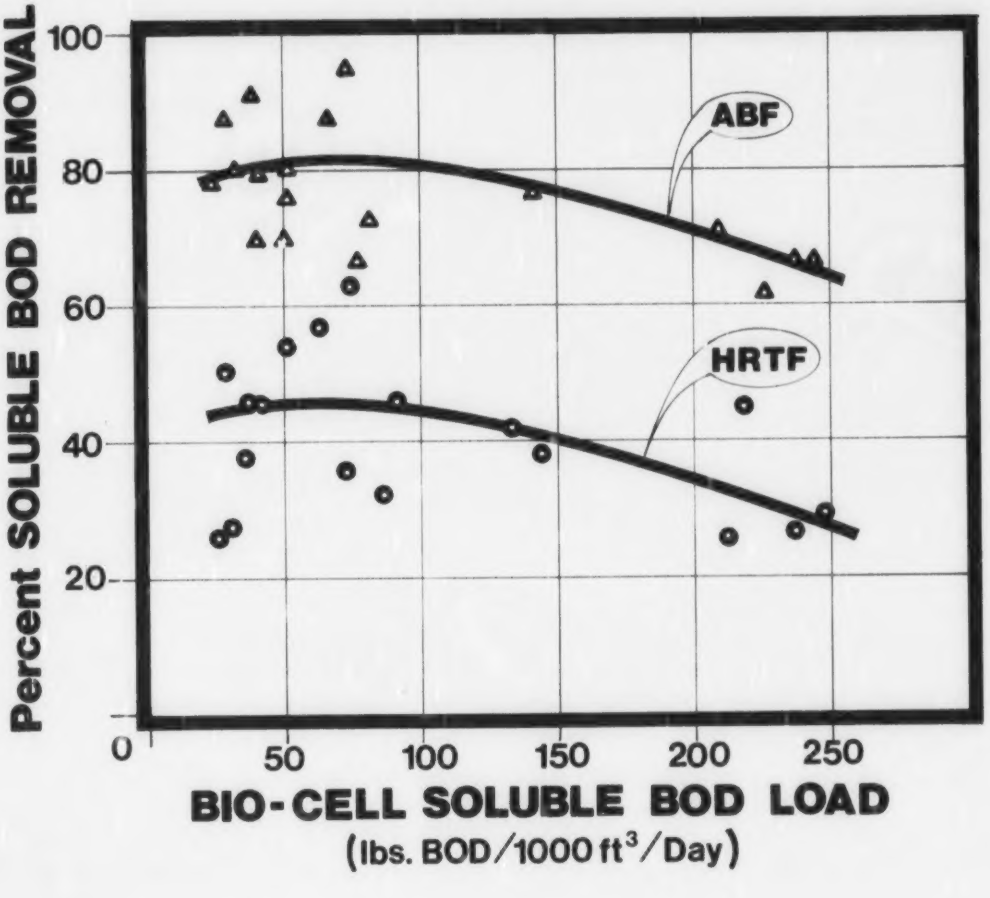


Figure 3.

Further details of the studies of combined food processing/domestic wastewater at Tracy and Turlock are given later in this paper.

EXPERIENCE WITH ABF ON FOOD PROCESSING WASTES

Pilot Plant Studies

Numerous pilot plant studies have been conducted to demonstrate the effectiveness of the ABF process on various types of food processing wastewaters. Some of the results of these studies are shown in Table 1 and are discussed in further detail below.

Corvallis, Oregon (1974); Beets/Corn/Domestic (4): The wastewater composition tested during the study was 46% corn, 26% beets, and 28% domestic, based on BOD_5. As shown in Table 1, the system loadings were extremely high in this study, with the Bio-Cell load over 240 lb/BOD_5/day/1000 cu.ft., and aeration detention time less than 45 minutes. Despite the high loadings of highly soluble carbohydrate wastes, the ABF system maintained excellent settling characteristics, with the SVI below 60 for all three runs. Sludge production ranged from 0.5 to 0.6 lb VSS/lb BOD_5 removed.

Tracy, California (1972); Domestic/Tomato/Potato (7): During the canning portion of the study, the primary industrial contributor was from tomato processing and the BOD of the waste was 92% soluble. ABF was compared with HRTF-activated sludge and pure oxygen activated sludge systems. ABF with horizontal media was selected as the most efficient system studied, and consistently provided an effluent with less than 20 mg/l BOD, sludge settling velocities greater than 6.0 feet per hour, and SVI less that 75 ml/gm.

Turlock, California (1975); (5)(6): This 1975 study included domestic wastes combined with poultry processing, tomato cannery, apricot, peach, and yam processing wastes. The results in Table 1 are broken down into five phases representing different mixes of these wastewaters. In this study, as in Tracy, ABF was compared with pure oxygen activated sludge and HRTF-activated sludge. ABF produced the highest quality effluent, and based on an economic analysis, has been selected for the full-scale plant.

Corvallis, Oregon (1975); Beets/Corn/Domestic (8): During the study of a prototype 50,000 gpd ABF package plant at Corvallis, seven weeks of data were collected, during which a significant portion of the waste was contributed by a local canner processing corn and beets. The wastewater characteristics were similar to those studied in Corvallis in 1974. The aeration basin detention time was about 2 hours. The Bio-Media depth was varied from 6 feet to 9 feet and the Bio-Cell organic loadings ranged from less than 50 to over 400 lb BOD_5/day/1000 cu.ft. Excellent effluent quality and stable mixed liquor characteristics were observed throughout the range of loadings tested.

Full Scale Plants

Table 2 contains a partial listing of full scale plants utilizing ABF for treatment of combined food processing/municipal or straight food processing wastes. Summaries of operating data from the Idaho Falls, Forest Grove, Madera and Hood River plants are summarized in Table 3.

TABLE I
OPERATING CONDITIONS AND RESULTS
PILOT PLANT STUDIES

	Influent			Effluent			Bio-Cell		Aeration Basin						
	BOD	SBOD	TSS	BOD	SBOD	TSS	#BOD/1,000 cu ft/day	Depth ft	MLSS	MLVSS	ISR*	SVI	Time Hrs	System F/M	$\frac{\#O_2}{\#BOD_5}$
Corvallis, Oregon (1974)															
Beets (26%), Corn (46%), Domestic (28%)	349	278	161	49	31	44	300	14	4,110	3,210	6.2	45	0.55	4.74	0.19
	415	302	194	49	24	53	281	14	3,500	2,860	5.5	56	0.73	4.75	0.15
	344	271	143	48	25	51	242	14	3,110	2,520	8.3	50	0.67	4.91	0.19
Tracy, California															
Tomato/Potato/Domestic	437	400	163	16	4	23	192	14	3,650	2,290	7.8	61	6.20	0.77	0.63
Turlock, California															
Domestic/Poultry	180	72	98	25	5	25	72	19		1,430	-	-	2.80	1.07	-
Domestic/Poultry/Apricot	311	177	154	23	4	23	116	19		2,530	5.9	73	6.20	0.80	1.10
Domestic/Poultry/Tomato/Peach	314	193	193	11	3	11	219	19		3,120	5.3	69	3.40	0.75	0.70
Domestic/Poultry/Tomato	180	69	211	7	3	10	122	19		2,790	3.2	74	3.40	0.47	1.10
Domestic/Poultry/Yam	295	121	260	15	3	19	157	19		2,580	2.7	105	4.20	0.61	0.70
Corvallis, Oregon (1975)															
Beets/Domestic	170	119	158	14	6	16	118	9	3,220	2,160	7.2	51	2.00	1.01	0.50
Corn/Beets/Domestic	337	241	153	14	5	16	302	6-9	3,860	2,970	2.8	57	1.90	1.48	0.30

*ISR = Initial settling rate, ft/hr.

TABLE 2
PARTIAL LIST OF ABF PROCESS INSTALLATIONS
FOR FOOD PROCESSING WASTE

Name/Location	Process*	Design Flow	Waste Description	Industrial Contribution	Startup
Madera, California	ABF (w/o Aer.)	7.0 MGD	Olive/Domestic	25%	Mar 1973
Aberdeen, Idaho	ABF	0.6 MGD	Potato/Domestic	85%	Oct 1973
Idaho Falls, Idaho	ABF	17 MGD	Potato/Domestic	80%	Jan 1974
Ore-Ida Foods Ontario, Oregon	ABF	3.5 MGD	Potato	100%	Apr 1973
Crete, Nebraska	ABF (w/o Aer.)	1.0 MGD	Corn/Domestic	80%	Jan 1975
Hood River, Oregon	ABF	3.5 MGD	Fruit/Domestic	85%	Apr 1975
Forest Grove, Oregon	ABF	5.0 MGD	Fruit/Vegetable/Domestic	90%	May 1975
Twin Falls, Idaho	ABF	8 MGD	Potato/Domestic	80%	May 1976
Tracy, California	ABF	10.2 MGD	Tomato/Potato/Domestic	85%	Feb 1977
Oscar Mayer & Company Perry, Iowa	ABF	1.2 MGD	Meat Packing	100%	
Consolidated Badger Marshfield, Wisconsin	ABF (w/o Aer.)	0.15 MGD	Dairy	100%	Jun 1977

*ABF: Bio-Cell followed by aeration
ABF (w/o Aer.): Bio-Cell with sludge recycle; no aeration.

TABLE 3

ABF INSTALLATIONS
PLANT OPERATING CONDITIONS AND RESULTS

	No. Months	Q MGD	Influent		Effluent		Bio-Cell Load lb BOD/Day/ 1,000 Cu Ft
			BOD	TSS	BOD	TSS	
Idaho Falls, ID	34	8.5	255	207	12	8	50
Forest Grove, OR	15	2.2	440	120	12	15	37
Hood River, OR*	19	1.3	470	300	18	20	67
ABF Without Aeration							
Madera, CA**	21	2.3	246	135	35	14	51

*Three days of data omitted when sludge disposal system was inoperable in November, 1975; four days omitted when aeration basin off-line in September, 1976.

**Includes data during olive processing season only (9 months/year).

PROCESS CHARACTERISTICS AND DESIGN CONSIDERATIONS

The factors influencing ABF system performance are numerous. As a result, classical fixed-film and suspended growth analyses are not easily applied to system design. Fortunately, empirical approaches have been used with success.

A convenient analytical tool which will be used herein quantifies the system organic loading in terms of System F/M (9). This is defined as:

$$\text{System F/M} = \frac{\text{lb Influent BOD/day to Bio-Cell}}{\text{lb MLVSS in Aeration Basin}}$$

This equation does not include the mass of biological solids contained in the Bio-Cell or clarifier. Because of this, the numerical value of the System F/M will be several times greater than those normally used in activated sludge process design.

The following sections deal with effect of loading on process performance.

Effluent Quality

In Figure 4 the effects of System F/M on ABF effluent quality for a variety of wastewaters are shown graphically. No marked deterioration of final effluent quality can be seen over the wide range of loadings represented. More biologically resistant organic materials may affect effluent quality.

Mixed Liquor Settleability

As discussed previously, the design of conventional activated sludge systems are often limited by the settleability of the mixed liquor. This is especially true for food processing wastes in which high soluble organic content wastes contribute to sludge bulking (1). In Figure 5, the relationship of system loading in terms of System F/M is shown as it affects the settling characteristics of the mixed liquor in the ABF process. The values of the initial settling rate and sludge volume index remain excellent even at System F/M's greater than 4.0. Sludge settleability, therefore, does not limit the allowable System F/M for the ABF process.

Aeration Basin Oxygen Requirements

Oxygen requirements for the ABF aeration basin can be identified as follows:

$$\text{Aeration Basin Oxygen Demand} = \frac{\text{lb. } O_2 \text{ to Aeration Basin}}{\text{lb. BOD Removed in System}}$$

As in the System F/M definition, the influence of the Bio-Cell is not considered in this equation. The denominator is computed as the total BOD to the Bio-Cell minus the clarifier effluent soluble BOD. For ease of analysis, oxygen demand data are tabulated and presented as shown in Figure 6, in which System F/M is plotted versus aeration basin oxygen demand. It can be seen that the oxygen demand decreases as the System F/M increases. The data indicate that aeration power requirements are minimized by selection of the System F/M at a value above 0.8. Nitrification is observed to occur at

Effect of System F/M on ABF Effluent

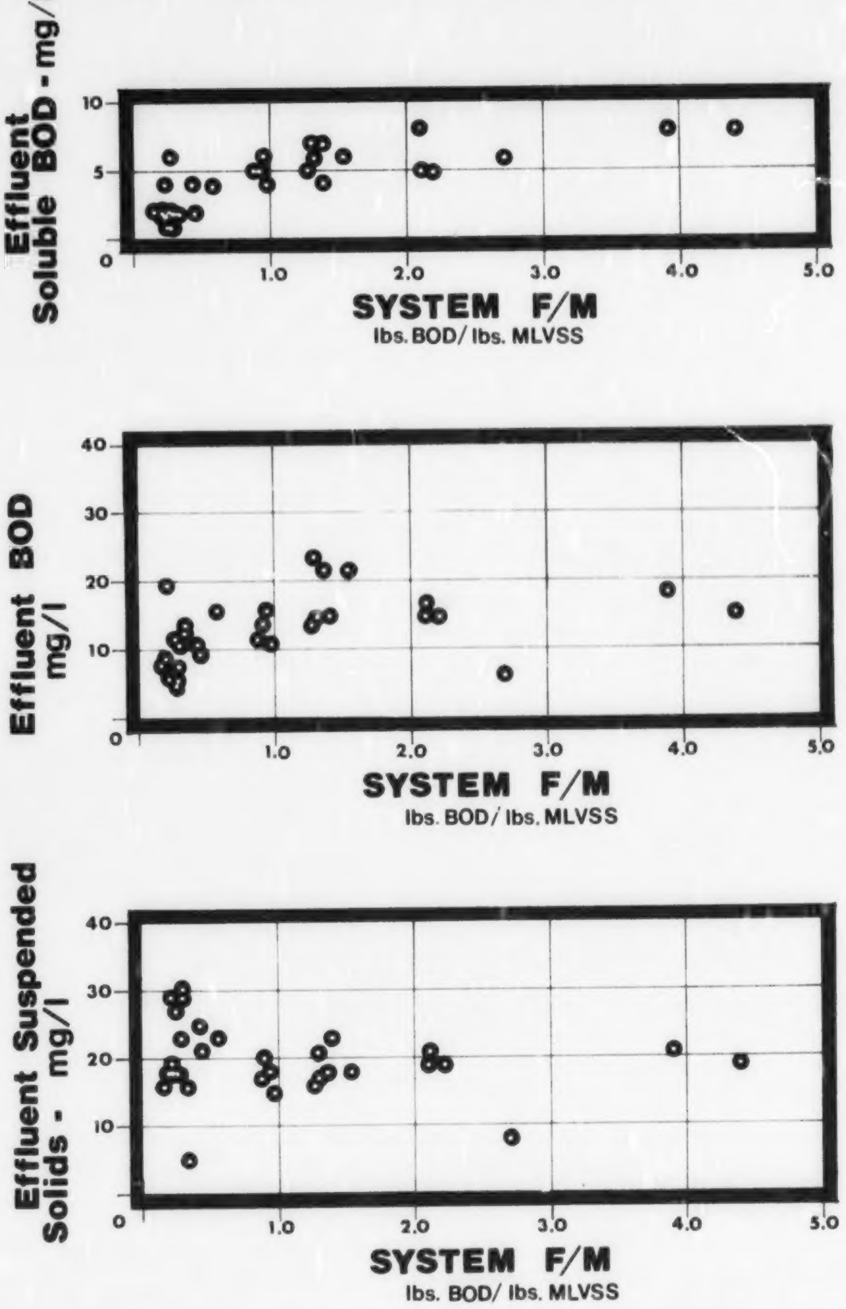
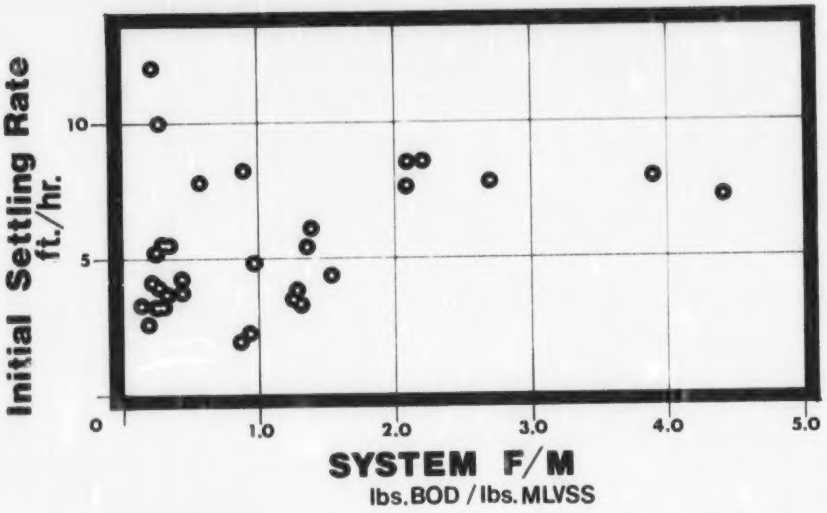


Figure 4.

Effect of System F/M on Settleability of ABF Mixed Liquor



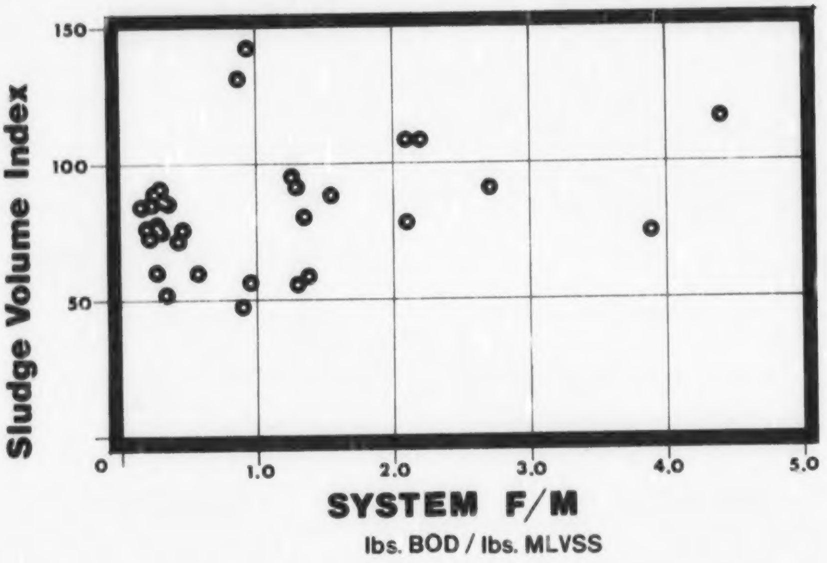


Figure 5.

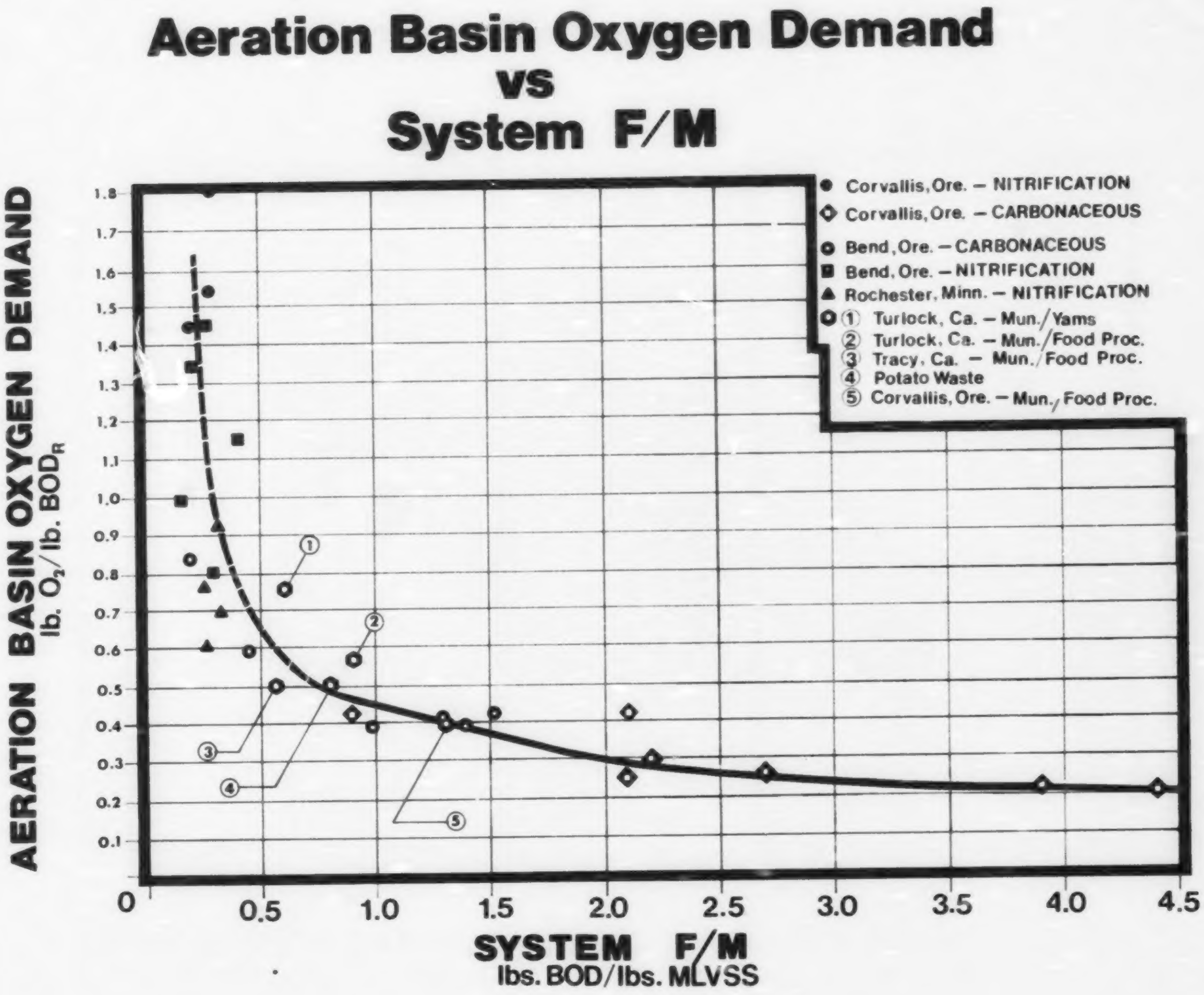

Aeration Basin Oxygen Demand
vs
System F/M
AERATION BASIN OXYGEN DEMAND
lb. O₂/lb. BOD_R
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
SYSTEM F/M
lbs. BOD/lbs. MLVSS
● Corvallis, Ore. – NITRIFICATION
◇ Corvallis, Ore. – CARBONACEOUS
○ Bend, Ore. – CARBONACEOUS
■ Bend, Ore. – NITRIFICATION
▲ Rochester, Minn. – NITRIFICATION
○ ① Turlock, Ca. – Mun./Yams
② Turlock, Ca. – Mun./Food Proc.
③ Tracy, Ca. – Mun./Food Proc.
④ Potato Waste
⑤ Corvallis, Ore. – Mun./Food Proc.
①
②
③
④
⑤

Figure 6.

System F/M less than 0.6, hence the increased oxygen demand and greater degree of data scatter.

Bio-Cell Loading and Media Depth

The ABF aeration basin oxygen requirements, effluent quality, and mixed liquor characteristics have not been found to be appreciably affected by the Bio-Cell organic loading. The relationships observed in Figures 4, 5, and 6 hold true for loadings ranging from 50 to 300 lb BOD/day/1,000 cu. ft. Normal design values range from 100 to 350 lb/day/1,000 cu. ft, with a value of 200 at average day loading being most commonly used. Media depth can range from 7 feet to 22 feet, again with no deleterious effect on performance.

Typical ABF System Design Criteria

Table 4 shows typical design criteria for the ABF process which may be applied to most domestic/food processing waste, treatment situations. It should be noted that design criteria are specific to the type of wastewater and that some difficult-to-treat wastes may call for more conservative design in order to meet stringent effluent standards.

Power Requirements For ABF Process

The ABF process can offer significant power savings compared to conventional processes. The reason for this is the high organic removal that occurs in the Bio-Cell in relation to the power input required for pumping.

Table 5 shows a typical comparison between ABF and activated sludge for a food processing waste. All assumptions are indicated and reflect typical design values. For this example, the ABF system required about only half of the power input required for the activated sludge process. The magnitude of the power savings is dependent upon the particular conditions but generally falls in the range of 25 to 55 percent.

Operational Flexibility

Quite often, consideration must be given to treatment of wastes not only during design conditions but also for time periods during which reduced organic loadings are expected. Because the ABF process consists of two stages, a great deal of operational flexibility is available without the need for construction of multiple Bio-Cells, aeration tanks, etc.

A good example of the operational flexibility which can be designed into the plant by simple piping installations is shown in Figure 7, which shows the alternatives available at the Forest Grove, Oregon, Wastewater Treatment Plant. For low organic loadings, the system can be operated as either a standard high-rate trickling filter or a conventional activated sludge system. For moderate loadings, the conversion can be made to ABF without aeration or high-rate trickling filter with activated sludge. At high loadings, a standard ABF with aeration system is utilized. Thus, operation costs and operational complexity can be matched to the incoming loading.

TABLE 4.
Typical ABF Design Criteria

Effluent Criteria	Units	Typical Value	Range
BOD$_5$	mg/l	20	10-30
Suspended Solids	mg/l	20	10-30
NH$_3$N (Nitrification Design Only)	mg/l	1.0	0.5-2.5
Bio-Cell Parameters			
Organic Load	lb BOD/Day/ 1,000 cu.ft.	200	100-350
Media Depth	Feet	14	7-22
Hydraulic Parameters			
Sludge Recycle	(1)	0.50	0.3-1.00
Bio-Cell Hydraulic Load	gpm/sq.ft.	3.5	1.0-5.5
Bio-Cell Recycle - as required to maintain media wetting rates.			
Aeration Parameters			
System F/M (2)			
Carbonaceous Design	lb. BOD/day/lb.VSS	1.4	0.8-3.5
Nitrification	"	0.3	0.2-0.6
Oxygen Utilization			
Carbonaceous Design	lb O$_2$/lb BOD rem.	0.37	0.2-0.8
Nitrification (3)	"	0.65	---
MLVSS Concentration	mg/l	3,000	1500-4000
MLSS Concentration	mg/l	4,000	2000-5000
Oxygen Uptake Rate	mgO$_2$/l-hr	65	50-100
Clarifier Parameters			
Overflow Rate	gpd/sq.ft.	600	300-1200
Solids Loading	lbs/hr/sq.ft.	1.25	0.5-2.0
Sludge Production			
Carbonaceous Design	lb VS/lb BOD rem.	0.65	0.5-0.75
Nitrification	lb VS/lb BOD rem.	0.45	0.3-0.55

---

(1) Based on average flow
(2) Based on primary effluent BOD$_5$ (process influent) loading to MLVSS in aeration basin
(3) Total O$_2$ required = Carbonaceous + 4.6 lbs. O$_2$/lb NH$_3$-N removed

TABLE 5.
COMPARATIVE ANALYSIS OF POWER REQUIREMENTS FOR ABF AND ACTIVATED SLUDGE

TREATMENT CONDITIONS AND REQUIREMENTS

Flow = 2.0 MGD
BOD = 500 mg/l (8,340 lb/day)

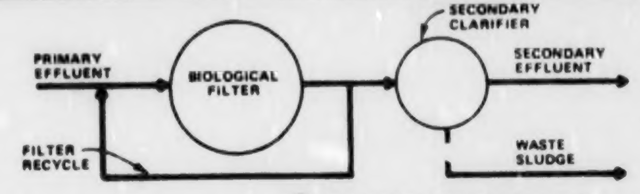
Effluent Required: 30 mg/l BOD
30 mg/l TSS

	ABF*	Activated Sludge**
Bio-Cell Pumping Requirement, gpm (TDH = 22 feet)	2,980	-
Bio-Cell Horsepower	22	-
Aeration Oxygen Supply, lb/hr	125	348
Aeration Horsepower	63	174
Total System Horsepower	85	174

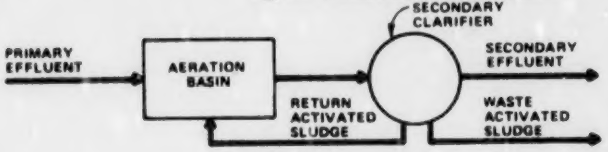
---

*Assumed: Bio-Cell loading = 200 lb BOD$_5$/1,000 cu ft/day
Media depth = 14 ft; pump efficiency = 75%
Flow sufficient to provide 1.0 gpm/sq ft wetting rate
System F/M = 1.5; O$_2$ required = 0.37 lb/lb BOD$_5$ removed

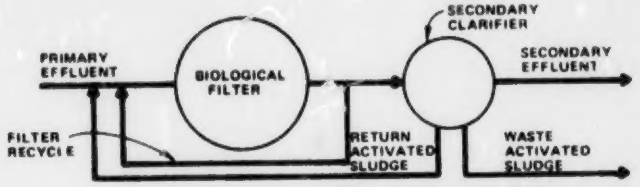
**Assumed: 1.0 lb O$_2$/lb BOD$_5$ required
Aerator field transfer efficiency of 2.0 lb O$_2$/hp-hr


SECONDARY CLARIFIER
PRIMARY EFFLUENT
BIOLOGICAL FILTER
SECONDARY EFFLUENT
FILTER RECYCLE
WASTE SLUDGE

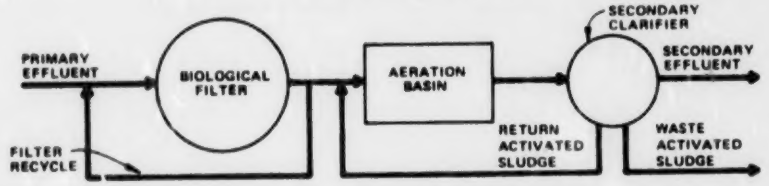
① HIGH RATE TRICKLING FILTER


SECONDARY CLARIFIER
PRIMARY EFFLUENT
AERATION BASIN
SECONDARY EFFLUENT
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

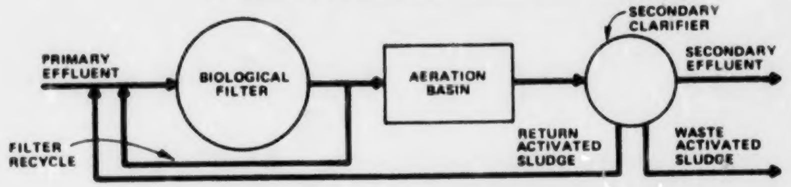
② ACTIVATED SLUDGE


SECONDARY CLARIFIER
PRIMARY EFFLUENT
BIOLOGICAL FILTER
SECONDARY EFFLUENT
FILTER RECYCLE
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

③ ACTIVATED BIOFILTER


SECONDARY CLARIFIER
PRIMARY EFFLUENT
BIOLOGICAL FILTER
AERATION BASIN
SECONDARY EFFLUENT
FILTER RECYCLE
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

④ HIGH RATE TRICKLING FILTER–ACTIVATED SLUDGE


SECONDARY CLARIFIER
PRIMARY EFFLUENT
BIOLOGICAL FILTER
AERATION BASIN
SECONDARY EFFLUENT
FILTER RECYCLE
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

⑤ ACTIVATED BIOFILTER – ACTIVATED SLUDGE

FIGURE 7

FOREST GROVE WASTEWATER TREATMENT PLANT

SCHEMATIC DIAGRAMS
SECONDARY TREATMENT ALTERNATIVES

SUMMARY

The ABF process offers a viable alternative for secondary treatment of food processing wastes. The system offers a high level of process stability, an important criterion in treatment of such wastes. Operational flexibility is inherent in the two-stage process.

System design criteria can be expressed in terms of Bio-Cell organic loadings and aeration basin loadings expressed as System F/M.

Significant power savings are achievable, due to the energy-efficient fixed-film Bio-Cell. Overall cost-effectiveness has been verified by others (10).

BIBLIOGRAPHY

1. Pipes, W. O., "Bulking of Activated Sludge." *Advances in Applied Microbiology*, 9 (1967), 185.

2. *Waste Reduction in Food Canning Operations*. Water Pollution Control Research Series No. 12060. FWQA, 1970.

3. *Trickling Filter Treatment of Fruit Processing Wastewaters*. Water Pollution Control Research Series No. 12060 EAE, U.S.E.P.A., 1971.

4. Owen, W. F., and Slechta, A. F., *Soluble Organic Removal with the ABF Process*, presented at the Third Annual Industrial Water and Pollution Conference and Exposition by WWEMA, Chicago, Illinois (April, 1975).

5. *1975 Wastewater Treatment Pilot Study for the City of Turlock, California*, CH$_2$M/Hill, (June, 1976).

6. Mattli, G. P., *Turlock, California, 1975, Pilot Plant Study of the ABF System*, Final Report for the City of Turlock, California (1975).

7. Williams, C. R., et al, *Results of Pilot Studies on Biological Treatment of Combined Food Processing/Domestic Wastewater at Tracy, California*, presented at the Annual Industrial Water and Pollution Conference and Exposition by WWEMA, Chicago, Illinois (March, 1973).

8. Booty, W. F., and Slechta, A. F., *Performance Evaluation 50,000 gpd ABF Package Plant*, Technical Publication No. KT-7272, Neptune Microfloc, Incorporated, Corvallis, Oregon (1976).

9. Slechta, A. F., and Mattli, G. P., *Activated Bio-Filter Process for Biological Wastewater Treatment*, Wastewater Treatment and Reuse Seminar, South Lake Tahoe, California (October, 1976).

10. Benjes, H., Jr., *Evaluation of Biological Wastewater Treatment Processes*, Wastewater Treatment and Reuse Seminar, South Lake Tahoe, California, (October, 1976).

SINGLE CELL PROTEIN FROM FOOD WASTES BY THE DEEP TANK PROCESS

by

M. L. Jackson* and C. C. Shen**

ABSTRACT

Recent papers describe the development of deep tank aeration-flotation for fermentation processing including the activated sludge process for wastewater treatment. Extension of the concepts, which include design factors for scale-up from laboratory-size equipment, to the production of single cell protein (SCP) is straightforward. The procedures are reviewed briefly and provide a design basis for oxygen supply and solids separation for the production of biomass.

The economics of SCP production presently are marginal when the carbon source is provided by petroleum derivatives. In contrast, the use of a suitable waste stream for the substrate is shown to offer a potentially profitable operation for the production of a protein material and simultaneously solve both liquid and solid waste disposal problems. An economic estimate of the conversion of 1.25 million gal/day of a potato waste on a continuous basis, and sale of SCP for animal feed indicates that the profit margin should be favorable, with income about double the annual cost of production. The largest unknown in the operation is that of the method and cost of drying, if indeed a dried product is desired.

Following the suggestion of another investigator, the economics of producing SCP by batch processing, possibly to avoid the need for sterilization of the incoming waste, were evaluated for the deep tank. Costs for tankage were increased two to three times over that for continuous flow, depending on processing variations, with capital costs increased 30 to 40%. However, operating costs remained unchanged with annual costs increased somewhat. This confirms a report for a similar process, in one case employing a potato waste, where potential profit was shown to be substantial.

SCP AND THE DEEP TANK PROCESS

The production of single cell protein (bacteria, yeast, fungi, termed SCP) is currently of much interest as it is expected to ultimately fulfill a major food need for mankind (1), either directly for human consumption or as an animal feed. Carbon sources for cell growth have been proposed from petroleum derivatives such as methane, alcohol, methanol and other compounds. The

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cost of these materials is such that the protein produced by microbial growth does not yet appear to be competitive although a large plant for the utilization of methanol is under construction. The use of a waste can provide a cheap substrate particularly, as with potato wastes, where appreciable amounts of phosphorus and nitrogen are also present for cell growth, thus saving the cost of added nutrients. Simultaneously treating a waste stream and solving a discharge problem by producing a product with a monetary value is especially attractive, and producing at a profit is an evaluation to be made.

The Environmental Protection Agency, acting on the Federal Water Pollution Control Act Amendments of 1972, imposed limitations for the discharge of wastewaters. These regulations apply to industrial and municipal sources alike and are particularly severe for situations where land availability is limited for conventional treatment. Further, capital investment and energy consumption are currently major considerations in new plant construction. Federal requirements are for best practical technology currently available (BPTCA) by July 1977, and best available technology economically achievable (BATEA) by 1983. These requirements impose a need to develop processes which are applicable to small land areas and are economical of capital and energy.

Past practice for the growth of organisms, aside from activated sludge and similar waste treatment plants, have not been directed toward large tonnage biomass production on a continuous basis. The problems are those of meeting the large oxygen demand, controlling the temperature of the fermenting medium, and separating, dewatering and drying the cell solids. Most fermentors currently in use employ mechanical agitation as part of the aeration and mixing process in the fermentor, usually in the form of a draft tube. Mechanical agitation appears to contribute to the heat generation problem, along with that from the oxidation process occurring in the fermenting medium.

Recent development of the deep tank aeration-flotation process offers a simple, less costly system which supplies oxygen at needed requirements, effects rapid mixing, and when the liquid depth is sufficient, provides dissolved gas for the flotation separation of solids (2,3,4,5). It also appears that some cooling can be effected by evaporation of water to the air input. This would be particularly useful for situations which operate at higher temperatures. The small liquid surface area of a deep tank facilitates temperature control, especially in cold climates.

The aeration tank is as tall as is feasible for ground support and space availability, preferably 50 feet or higher, with simple nozzle air inlets (holes in pipes) distributed uniformly over the bottom of the tank (3). The greater liquid depths do not add to air compression costs, but rather reduce the air volume requirement markedly because of the greater amounts of oxygen transferred during the longer rise times. A rough rule of thumb is that 1% of the inlet oxygen in air will be transferred to clean water for each foot of liquid depth as shown to be valid for depths to 70 feet in narrow columns (6,7). The depletion of the oxygen in the gas phase with increasing height is compensated by a corresponding increased pressure at the lower tank levels.

Mixing of the contents of tanks at 6- and 25-foot diameters has been shown to be rapid (2,3).

The dissolved air flotation method separates cells from the liquid and takes advantage of the inherent supersaturation of dissolved gases. Auxiliary equipment for a pressurized air-liquid contacting system, as required in conventional dissolved air flotation processes (8), is expensive and unnecessary. Reduced capital costs, compressor horsepower and pumping energy for extending tank height, as shown later, are reduced for the deep tank process which also has a much smaller land space requirement.

Problems associated with the recovery of SCP cells and the actual isolation of protein from the cells have been discussed (9). For cell separation, it is indicated that bacterial cells are more difficult to settle, in comparison to yeasts, and that centrifugal separation may not be suitable for a bacterial organism. The possibility of utilizing air flotation, where large cell size is not a necessary factor and may be less desirable, was not discussed. Dissolved air flotation creates a buoyancy of the cells which results in a separating force substantially greater than that for settling. In deep tank aeration, the gases have time to diffuse to the innermost portions of the cell flocs, and when the pressure is released, appear to effect an expansion which increases buoyancy.

The aeration-mixing-flotation process was demonstrated for the treatment of 0.7 million gal/day of a pulp-paper mill waste stream by the growth of suspended bacteria (3). Although the settling of bacteria by conventional gravity settlers is normally considered to be a slow process, the separation by flotation using the supersaturated dissolved nitrogen and carbon dioxide gases was demonstrated to be a rapid process giving an underflow stream of very low solids content. Flotation tank performance exceeded conventional design criteria and is attributed to gases diffusing to the floc interiors and expanding upon pressure release. Conventional air dissolving arrangements, where liquid-gas contact times are only a few minutes, do not permit such diffusion to occur. Supersaturation is also absent. Further, the cells were readily filtered on rotary belt equipment when admixed with settled fiber and wood fragments from a clarifier. The activated sludge contained some fiber from the input waste stream and this also was filtered directly on occasion without admixture to give a firm cake. This suggests that mixing fibrous food processing wastes with cell solids would facilitate dewatering and drying where these are available and have merit as an animal feed supplement.

FERMENTATION PROCESSING

The kinetics of cell growth, types of organisms which can be employed to produce protein, conventional design of fermentors, nutrients required, and related topics are beyond the scope of the present discussion. Such topics are treated in cogent form by Humphrey and others (10,11,12,13). Of interest here are the economics of producing protein materials from food processing wastes by relatively large continuous or batch processes. The deep tank aeration-flotation design, though employing higher compression and pumping pressures has been shown to be economical of both energy and capital for waste treatment (4). The costs of further processing and recovery of the cell solids in dry form for an animal feed supplement are of additional interest. In some cases, the cake produced may be sufficient as an animal feed without the need for drying and storage. It is assumed that the solids will have a protein content of about 50%, that they are bacterial in nature and therefore show the fastest growing rate, that the organism utilized either is developed from contaminating organisms or is from innoculation, and that growth conditions are controlled such that the desired organism predominates. This avoids the somewhat costly procedure of sterilization of the incoming waste liquid and air. It has been suggested that batch processing and proper control of pH and other conditions can be employed to avoid the need for aseptic culture (14).

The continuous process has not been employed extensively on a large scale and requires that the rate of growth of cells equal the dilution resulting from the incoming waste; otherwise washout of cells occurs and growth declines. Alternatively, the recycle of some cell solids to maintain high solids concentrations and high utilization rates can be employed. However, bacterial growths of mixed cultures have been carried out in the activated sludge process for many years although studies of the types of organisms adapting to particular waste and the related protein content have not been pursued extensively. Filamentous organisms occur in some situations under some conditions and lead to what is termed bulking or floating in settling equipment. With flotation separation this should not be a problem. A high protein content has been reported for some such organisms in the aeration basin treatment of potato wastes from a potato processing plant (personal communication).

DESIGN OF A CONTINUOUS DEEP TANK FERMENTATION PROCESS

To provide an approximate evaluation of the growth of a cell protein on potato waste solubles, calculations were made for a deep tank aeration-fermentation continuous process. The basis selected was a waste stream from a potato processing plant, which has been reported in detail, and for which an activated sludge lagoon system with mechanical surface aeration was constructed and employed as a demonstration project (15). Thus, a direct cost comparison can be made with a deep tank design. Potato wastes contain readily available carbon as the food source along with quantities of nitrogen and phosphorus sufficient for cell growth.

Table 1 gives the general conditions assigned for the production of single cell protein. The carbon:nitrogen:phosphorus ratios were reported to average 100:6.2:1.1 and such that no additional nutrients were needed because 80-90% BOD reductions were obtained.

The calculations employed a computer program which has evolved through several stages and gives deep tank designs in considerable detail (4,16), and for a wide range of variables. It provides tank and related costs, as a function of tank depth, and includes operating costs. The flotation, filtering and drying operations are constant factors and were added as a lump sum which was considered to be on the conservative (high) side of actual costs.

TABLE 1. CONDITIONS FOR CONTINUOUS SCP PRODUCTION

Waste flow	1.25 million gal/day
BOD concentration	1350 mg/l
BOD loading	14,100 lb/day
Cell solids produced	0.5 lb/lb BOD
Operation	9 months/year
Alpha (reduced O_2 transfer rate)	0.8
Dissolved oxygen residual	2 mg/l
BOD reduction	80%
Motor-compressor efficiency	0.75
Motor-pump efficiency	62%
Tank material	Carbon steel, rubber lined
pH	Neutral or acidic

Previous calculations (4, 16) indicate that tank and aeration costs do not increase significantly after a minimum annual cost condition is attained at about 40-50 feet. Table 2 gives the initial capital costs for tank, pumps, compressor, and piping as determined for tank heights from 22 to 82 feet. Certain operating costs, including the cost of electrical power for pumps and compressor, are also shown and are seen to vary little with depth with a minimum at 50 ft. The oxygen transfer efficiency increases with liquid depth, and less air needs to be compressed even though the pressure required is higher. Capital costs reach a minimum at 30-40 feet and then increase with tank depth, because compressor and piping costs decrease but tank and pump costs increase. However, the differences in costs are not large being only 15% greater at 82 ft as compared to 32 ft.

Table 3 summarizes the details of capital equipment costs, gives equipment sizes and indicates the results for one tank depth, taken as 80 feet to indicate that deep tank aeration is not a costly procedure. Acid resistant materials and lining for the tanks were specified.

TABLE 2. PARTIAL CAPITAL AND OPERATING COSTS FOR VARIOUS TANK HEIGHTS (1976 Dollars)

Tank Height Feet	Pump, Compressor, Tank and Piping Costs	12-month Power and Related Costs
22	$165,300	$16,900
32	162,700	16,800
42	166,500	16,700
52	169,300	16,400
62	175,800	16,500
72	182,500	16,600
82	189,200	16,700

TABLE 3. CAPITAL EQUIPMENT AND RECOVERY FOR SCP PRODUCTION UTILIZING A POTATO WASTE STREAM COMPARED TO LAGOON WASTE TREATMENT

	Deep Tank Aeration-Flotation (1976 Dollars)	Lagoon Surface Aeration-Clarification (14) (1970 Dollars)
Aeration volume	260,000 gal	3,750,000 gal
Liquid depth	80 ft	16 ft
Aerator size	24 ft diameter	70 x 150 ft plus 150 x 150 ft
Solids separator	450 sq ft (24 ft equivalent diameter, depth of 8 ft)	3850 sq ft (70 ft dia.) plus 710 sq ft (30 ft dia.)
Aeration time	4 hr	3 days
Solids separation time	21 minutes	
Tanks, pumps, compressor piping	$189,000	
Flotation unit, filter, drying	$215,000	
Added for contingency escalation, instrumentation	35%	
Total capital investment	$545,000	$646,000
ANNUAL FIXED COSTS	$ 67,600 (at 9% and 15 years)	$ 61,000 (at 7% and 20 years)

The total costs for equipment in Table 3 include added factors for contingency (20%), escalation (12%), and instrumentation (3%). Flotation tank costs were from an EPA publication (8), were much higher than needed for the deep tank system, and were therefore assumed to include costs for the filter and dryer. Capital costs and annual charges are seen to be similar for the SCP production facility and the lagoon treatment system even though the collection and drying of the cell solids is an added cost for an SCP product.

Table 4 gives estimated operating costs on the high side, and the total costs indicated are believed to represent a conservative estimate of the costs of production. Again, annual operating costs are similar for the two processes.

TABLE 4. OPERATING COSTS FOR SCP PRODUCTION UTILIZING A POTATO WASTE STREAM COMPARED TO LAGOON WASTE TREATMENT

(1976 Dollars)

	Deep Tank Aeration-Flotation	Lagoon Surface Aeration-Clarification
Installed power	120 hp	500 hp
Electrical power	0.01 $/kwh	0.01 $/kwh (est.)
Cost of electrical power	$6500	$23,500
Heat for drying	$7100	
Operating labor	$30,000	$18,100
Repair labor, materials	$1400	$13,500
Miscellaneous	$10,000	$10,000
ANNUAL OPERATING COSTS	$55,000	$65,200

Table 5 shows total annual costs for the production of 810 tons of SCP for the nine-month period considered in both cases. The selling price of the dried product would need to be $150/ton to meet production costs but at this figure there would be no cost for pollution control although at 80% BOD reduction the discharge would be higher than may be allowed. 90% BOD reduction could be achieved with little added costs as was demonstrated (3). With a selling price of $300, indicated to be a current reasonable value, the profit margin over production costs can be considerable, taxes excluded. Operation for 12 months per year, rather than nine as used for comparison with the lagoon process, would increase profit margins assuming a suitable substrate to be available.

TABLE 5. COMPARISON OF ANNUAL COSTS FOR SCP PRODUCTION AND LAGOON WASTE TREATMENT

(1976 dollars, 9 months)

Annual capital recovery	$ 67,600	$ 61,000
Annual operating costs	55,000	65,200
TOTAL ANNUAL COSTS	122,600	126,200
Disposal of Cell Solids	810 tons at $150/ton = production costs	14,000
NET COST	0	$140,300
PROFIT AT $300/ton	$122,600/year	(-$140,300)

Church, Erickson and Widmer (17) give costs for the growth of a fungus on a corn canning waste at conditions similar to the above for the potato plant waste: 1 million gal/day and 12,000 lb BOD/day loading for an income of $140,000 per year and a small profit with nutrient costs being high. The amount of solids produced and the assigned value were not indicated. A larger operation (17) showed a profit of 0.75 of the production costs (income = 1.75 x total annual production costs). This value compares favorably with the income ratio in Table 5 of about twice the cost of production. The possibility of producing a profit by growing single cell protein on a waste substrate appears to be favorable for some situations.

BATCH TANK OPERATION

The suggestion was made by Tomlinson (14) that non-aseptic operation on a batch basis could be an alternative to the need for sterilization to produce a given organism. Using the above potato waste example, a calculation of tank costs only was made for a fixed tank height of 50 feet with the number of tanks, and hence diameter, determined from cycle and fill times. For multiple tanks, the cycle time is the sum of the fill time, aeration time, and drain time (equal to the fill time) where

$$\text{Number of tanks} = (\text{cycle time})/(\text{fill time})$$

The design was such that the input to the series of tanks and the passage of the cell-liquid stream to the flotation tank were continuous but with the required number of tanks being filled, aerated or emptied as the sequence requires.

The basis of calculation was the continuous process with a residence time of four hours, waste feed of 1.25 million gal/day and a recycle rate of 25% of the float containing 2% solids. Thus, the flotation unit for batch processing would be the same as for the continuous process, the compressor duty would be about the same, and an additional pump would be required to maintain the pressure drop at the flotation cell inlet during final stages of drainage. Anticipating operation at low pH values, to suit certain types of organisms, the tanks were selected as rubber lined, and the additional pump made acid resistant.

Table 6 shows the number of tanks, and relative tank and total capital costs for various fill-drain and aeration times. Some aeration would also be accomplished during the fill time which is not included in the aeration times indicated. Tank costs increase from twice to nearly four times over the continuous arrangement. Total capital cost increases range from 1.2 to 1.7, the latter requiring ten tanks for a half-hour fill time, and the minimum being for a three-hour aeration time and 1.5 or 3.0 filling times. Certain advantages might accrue from the use of a combination of a larger number of tanks and a reasonably long filling time, as experience might dictate modifications of procedures, and surge storage could be accommodated by a variation of conditions.

TABLE 6. RELATIVE COSTS FOR BATCH TO CONTINUOUS FERMENTATION

Aeration Time	Filling Time	Number of Tanks	Diameter of Tanks	Relative Tank Cost	Relative Total Capital Cost
Continuous Fermentation					
4 hr		1	30 ft	1.0 ($97,000)	1.0 ($544,000)
Batch Fermentation					
4 hr	0.5 hr	10	11 ft	3.9	1.7
	1.0	6	15	3.0	1.5
	2.0	4	21	2.5	1.4
	3.0	3	30	2.7	1.4
3 hr	0.5 hr	8	11 ft	3.1	1.5
	1.0	5	15	2.5	1.4
	1.5	4	18	2.3	1.3
	3.0	3	26	2.3	1.3

The capital costs for batch treatment are seen to be considerably higher than for a continuous process, but if the need for sterlization is thus avoided, the problem of cost and availability of energy is reduced. Operating costs for the fermentation-separation step should be about the same for the batch and continuous processes.

EUROPEAN PRACTICE

Two recent papers (14) describe the laboratory investigation of a variety of food wastes and the growth of several types of "yeasts and other fungi" for protein yields. Wastes considered were malting, brewing, distillation, carmelization, beet sugar processing, canning (two types) and two different potato processing wastes. Sixteen different organisms were investigated but not all organisms for each waste. Conditions and results are reported briefly for operating pH, carbon to nitrogen ratio, carbon to phosphorus ratio, cell yield, percent substrate removal, final total organic carbon content, percent crude protein, and batch growth times. Also reported are the initial flow rates of the waste, BOD and COD concentrations, organic carbon content, nitrogen and phosphate levels and initial pH. For present purposes only the potato processing wastes are considered.

Certain details not described in the papers (14) but developed through personal correspondence, are that one potato processing waste, PP-1 is that from the production of frozen chips (U.S. terminology = french fry) and PP-2 is that for potato crisps (U.S. = potato chips). Both streams were "from the primary production lines" and were relatively clean and free from soil. PP-1 had passed through a crude starch removal stage.

Waste PP-1 at a flow of 420 gal/min had an initial BOD of 3150 mg/1 and COD of 3800, organic carbon of 1510, pH 4.5, and substantial nitrogen and some phosphate with C/N = 10.3 and C/P = 250. The reduction of the substrate was from 60 to 80%. Additions of phosphate to give ratios of C/P of 35 and 70 made little difference in substrate reductions or in crude protein contents of 40 to 56% on cell yields of 300 to 600 mg/1.

The waste designated PP-2, at a flow of 290 gal/min had a BOD - 3250, COD = 5800, organic carbon = 2280, C/N = 162, C/P = 36 and pH = 4.8. Laboratory results for three organisms gave substrate removals of 60 to 80%, cell yields of 2000 to 3500 mg/1, and crude protein contents of 20 to 45%.

A personal communication concerning the wide difference in cell solids from PP-1 and PP-2, a factor of 10 in some cases, indicated that no reason was known. This was indicated as especially difficult to understand because of the high utilization of BOD and the similar reductions in the total organic carbon. A toxicity problem might be suspected if the substrate reductions were substantially less for PP-1.

In a second paper (14) the non-aseptic batch culture was proposed and tested on a laboratory scale of six wastes each with an organism selected from the previous screening procedures. The procedure was to investigate whether contamination of organisms could be minimized by close control of operating conditions rather than by sterilization of the feed waste. Low contamination was demonstrated by imposing three conditions: at innoculation the desired organism greatly out-numbered the contaminating organisms, the batch operation was completed in a relatively short time, and the pH was optimum for the desired organism. Operating at a low pH and the method of innoculation were important factors in minimizing contamination.

The results of an economic feasibility study were also presented for an arrangement similar to that for aeration in an activated sludge treatment plant with added costs for dewatering and drying which were on a conservative basis. Operating costs were based on an oxygen transfer efficiency of 1.6 lb O_2/hp-hr at 2.2 cents/kwh. The life of the plant was taken as 10 years and interest rates on capital costs were computed at both 10 and 15%. A survey of the value of protein solids was stated to vary from $200 to "at least" $400 per ton (18) with $300/ton selected as a reasonable figure for estimation purposes.

Estimates of annual costs were made for the six wastes for conventional activated sludge treatment and for plants for the production, drying and sale of the protein solids. Design details were not provided. In all cases, receipts for SCP production paid for the annual costs which were in excess over that for conventional treatment except in one case where costs were just met. However, considering annual receipts and annual costs for SCP production, without an allowance for needed conventional treatment, a profit was shown in only two cases but PP-2 wastes showed an annual income more than twice that for the annual costs of production. Based on 1975 costs in British pounds, and using an approximate exchange of $2.00/pound (now about 1.75) the capital investment was $740,000, and annual costs $250,000 for the SCP production plant at 15% interest. The estimated annual receipts were $540,000.

Imperial Chemical Industries, in England, has been interested in the growth of single cell protein on methanol, and recently recognized the merit of deep tank aeration for fermentation and growth of SCP (19). This confirms the results of present work as to the feasibility of the procedure, the merit for large scale processing, and quite important, the ability to supply large quantities of molecular oxygen from air and meet the demand of the organisms. The simplicity of the procedure is recognized which does not require the use of mechanical agitators.

LITERATURE CITED

1. Scrimshaw, N. S. and D. I. C. Wang, "Protein Resources and Technology: Status and Research Needs", National Science Foundation, No. NSF RA-T-75-037, Dec. (1975).

2. Jackson, M. L. and C. C. Shen, "Aeration and Mixing for Deep Tank Fermentation", presented at the 69th Annual meeting, American Institute of Chemical Engineers, Chicago, Dec. 1976 (under review for publication in the AIChE Journal).

3. Jackson, M. L., C. C. Shen and C. Plopper, "Deep Tank-Flotation Biological Treatment: Groundwood Paper Mill Wastewater", Water Pollution Control Federation meeting, Seattle, October 1976 (under review for publication).

4. Shen, C. C. and M. L. Jackson, "Economics of Deep Tank Aeration-Flotation for Wastewater Treatment", a report to the Northwest Pulp and Paper Assn., Feb. 1977 (to be submitted for publication).

5. Jackson, M. L., "Continuous Fermentation Process and Apparatus", patent, assigned to the Idaho Research Foundation, May, 1976.

6. Urza, I. J. and M. L. Jackson, "Pressure Aeration in a 55-foot Bubble Column", I&EC Proc. Des. and Develop., 14, 106 (1975).

7. Jackson, M. L., James, D. R. and B. P. Leber, "Oxygen Transfer in a 23-Meter Bubble Column," AIChE Symp. Ser., WATER-1975, No. 151, Vol. 71, 159 (1975).

8. Environmental Protection Agency, "Sludge Treatment and Disposal," (1974) and "Suspended Solids Removal," (1975).

9. Wang, D. I. C., "Protein Recovery Problems," in "Engineering of Unconventional Protein Production," Chemical Engineering Progress Symposium Series, No. 93, Vol. 65, p. 66 (1969).

10. Humphrey, A. E., "Current Developments in Fermentation", Chemical Engineering, Dec. 9 (1974), p. 98.

11. Humphrey, A. E., "Starvation: Chemical Engineering Can Help Fight It", Chemical Engineering, July 18, (1966), p. 149.

12. Aiba, A., A. E. Humphrey, N. F. Mills, "Biochemical Engineering", second ed., Academic Press, 1973.

13. Humphrey, A. E., "Engineering of Single Cell Protein: State of the Art," Chem. Engr. Prog. Symposium Series, No. 93, Vol. 65 (1969), p. 60.

14. Tomlinson, E. J., "The Production of Single-Cell Protein from Strong Organic Waste Waters from the Food and Drink Processing Industries - 1. Laboratory Cultures; 2. The Practical and Economic Feasibility of a Non-Aseptic Batch Culture:, Water Research, 10, 367, 372 (1976).

15. French, R. T., Co., "Aerobic Secondary Treatment of Potato Processing Wastes," EPA Program, 12060 EHV, WPRD 15-01-68, 1970.

16. Edwards, L. L., Leber, B. P., Jr., and M. L. Jackson, "An Economic Evaluation of Deep Tank Aeration," AIChE Symp. Ser., WATER-1975, No. 151, Vol. 71, 154 (1975).

17. Church, B. D., E. E. Erickson, and C. M. Widmer, "Fungal Digestion of Food Processing Wastes", Food Technology, 27, 36 (1973).

18. Smith, R. N., P. Houslay and A. Whitaker, "Recycling of Food Wastes - Microbiology and Economics," J. Applied Chem. and Biotechnology, 24 376 (1974).

19. Anon., "ICI to Scale Up Single Cell Protein Process," Chemical Engineering News, p. 25, Oct. 11, (1976).

EVALUATION OF INSTANT NOODLES PROCESSING WASTEWATER CHARACTERISTICS AND TREATMENT ALTERNATIVES

by

P. Y. Yang* and Victor S. Luis, Jr.**

INTRODUCTION

An instant noodles processing plant located on the industrial estate at Minburi, Thailand, produced instant noodles at the rate of 1,670 packages per 8-hour day of operation, with each package containing 30 x 60 gram bags of instant noodles.

Water consumption in the factory was primarily for soup-making, process equipment washing, removing spent alkali from the oil used for baking and boiler feed. Most of the washings inside the factory were channelled into a common drainage system which in turn discharged into a rectangular concrete collecting tank. The contents of this tank was pumped out daily to a nearby canal. Toilet wastewaters and floor washings from the administrative office were flown to a separate sewer.

Factory wastewater, containing substantial quantities of biodegradable organic material, was discharged without treatment to the nearby canal at locations SP1, SP2 and SP3 shown in Figure 1. The present study was proposed to determine the quality and quantity of the wastewater and recommend possible treatment alternatives to remove effectively oil, solids and organic matter. It was expected the results of this study would provide basic criteria for functional design of wastewater treatment processes.

EXPERIMENTAL METHODS

Wastewater characteristics and treatment studies were included in the present study.

Wastewater Characteristics

The factory washing contained a mixture of soap, grease (from chicken dressing and oil refining), flour and noddle strands.

Daily samples of wastewaters from SP1, SP2 and SP3 in Figure 1 were collected continuously for a period of 2 weeks, but not on Sundays (the factory was closed on Sunday). The quantity of the wastewater was determined by measuring the depth in the receiving tank (fixed volume) at SP1, SP2 and SP3. The quality of the wastewater, including solids, BOD_5, COD, nitrogen, phosphorus, grease and pH, was analyzed using the procedures recommended in Standard Methods (1).

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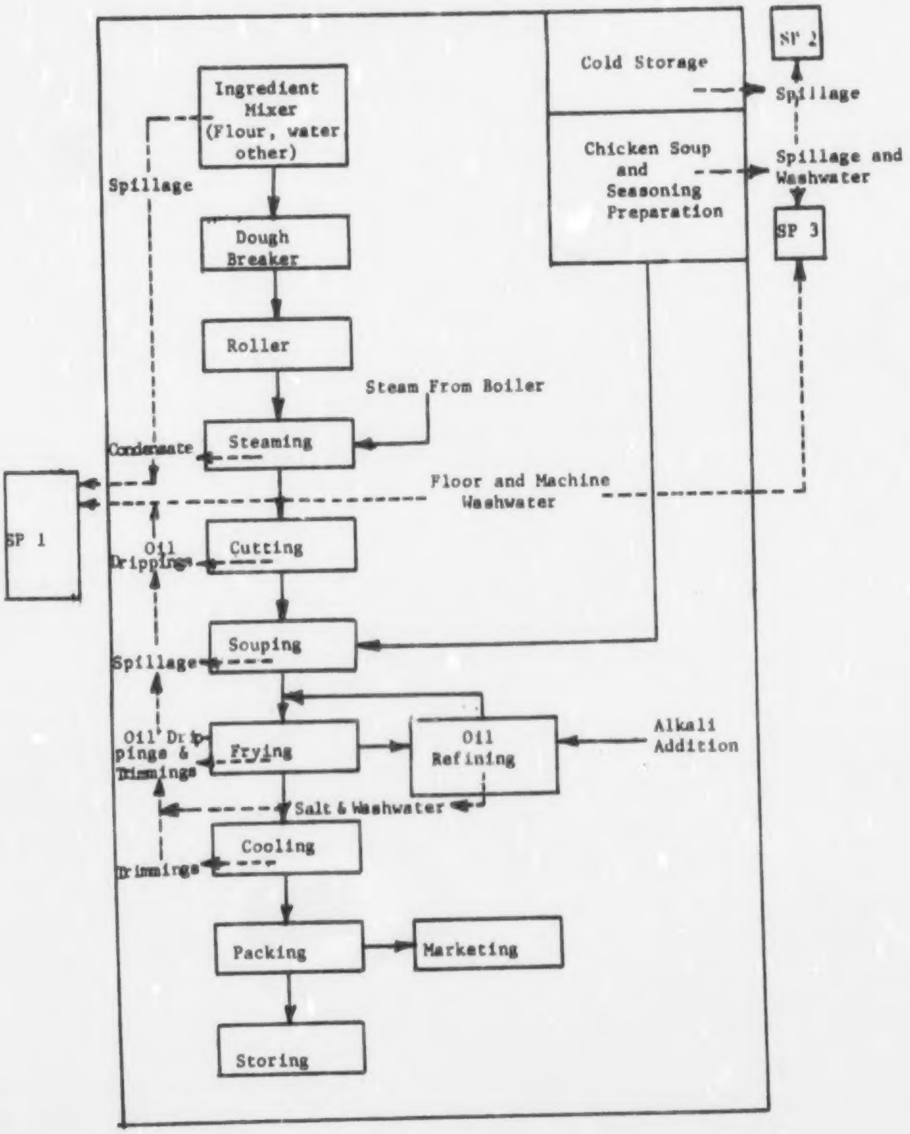
Cold Storage
SP 2
Spillage
Ingredient Mixer (Flour, water other)
Chicken Soup and Seasoning Preparation
Spillage and Washwater
SP 3
Spillage
Dough Breaker
Roller
Steam From Boiler
Condensate
Steaming
Floor and Machine Washwater
SP 1
Oil Drippings
Cutting
Souping
Spillage
Oil Drippings & Trimmings
Frying
Oil Refining
Alkali Addition
Salt & Washwater
Cooling
Trimmings
Packing
Marketing
Storing

Figure 1. Plant Layout Showing Process Flow, Sources of Washwater and Location of Sampling Points (SP 1, SP 2, SP 3).

Wastewater Treatment Studies

The studies were conducted in three phases:

1. Sedimentation/Flotation Study - Experiments were carried out using a sedimentation column 127 cm high and with square cross sectional surface area of 161.3cm^2, as shown in Figure 2. The column was equipped with sampling points, spaced at 20.3 cm intervals with the first sampling point located 4 cm below the overflow pipe at the top of the column. Simultaneous samplings were made from all points immediately after filling the column and then at 5, 10, 20, 40, 60, 90 and 120 minutes lapsed times. Withdrawn samples were analyzed for suspended solids, total COD and grease.

2. Coagulation Study - The jar test method was adopted for the coagulation study. Alum was the chemical coagulant used and flocculation was carried out with a stirring machine manufactured by Phipps and Bird Laboratory, Richmond, Virginia. The optimal pH and alum dosage to achieve suitable removal of turbidity were evaluated by using the Hach Laboratory Turbidimeter, manufactured by Hach Chemical Co., Ames, Iowa. Color, COD and grease were the other parameters whose removals were determined in this phase of the work.

3. Biological Treatment Study - This phase of the work was divided into two parts dealing with batch and continuous-flow biological treatment processes. In the batch study, acclimatized organisms were developed using instant noodle wastewater as substrate. Two batch activated sludge units were then fed with different forms of the factory wastewater. One unit received the raw waste, while the other unit received wastewater which had been subjected to a process whereby 60-86 percent of the grease content had been removed. Analyses for COD, BOD$_5$, suspended solids and grease were carried out at different time intervals. In the continuous-flow completely mixed biological treatment study, the extended aeration activated sludge process shown in Figure 3 was used. Two aeration tanks were used and fed with two forms of the factory wastewater which had been used in the batch treatment study. Again, COD, BOD$_5$, suspended solids and grease were analyzed in the feed, mixed liquor and effluent.

RESULTS

1. Wastewater Characteristics

Since the factory only operates 8 hours a day, 6 days a week and uses small quantities of water for washing, the average daily flow rate was considered suitable for treatment process design. This average daily rate was observed to be small, with a mean of 1.24 ± 0.17 m^3/day.

Originally, washings from the factory were discharged at three locations, designated SP1, SP2, SP3 in Figure 1. A pond near the factory received the wastewater from SP2 and SP3. At that time, the wastewater characteristics at the three points were as shown in Table 1. Subsequently it was found that the flow rates at SP2 and SP3 were small (< 0.022 m^3/day) compared with the flow rate at SP1. Moreover, from August

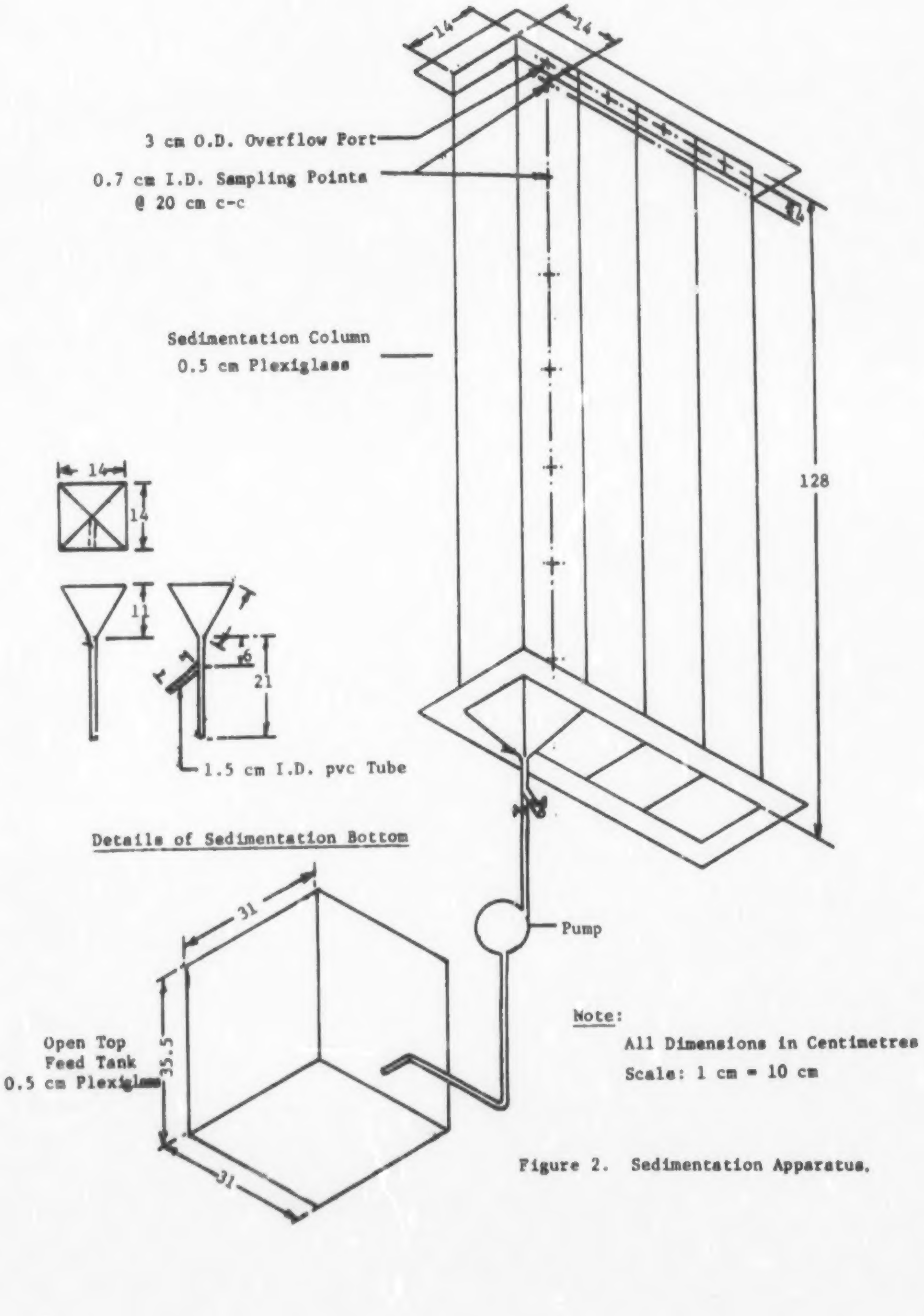
14
14
3 cm O.D. Overflow Port
0.7 cm I.D. Sampling Points
@ 20 cm c-c
14
Sedimentation Column
0.5 cm Plexiglass
128
14
14
11
6
21
1.5 cm I.D. pvc Tube
Details of Sedimentation Bottom
31
Pump
35.5
Open Top
Feed Tank
0.5 cm Plexiglass
31
Note:
All Dimensions in Centimetres
Scale: 1 cm = 10 cm

Figure 2. Sedimentation Apparatus.

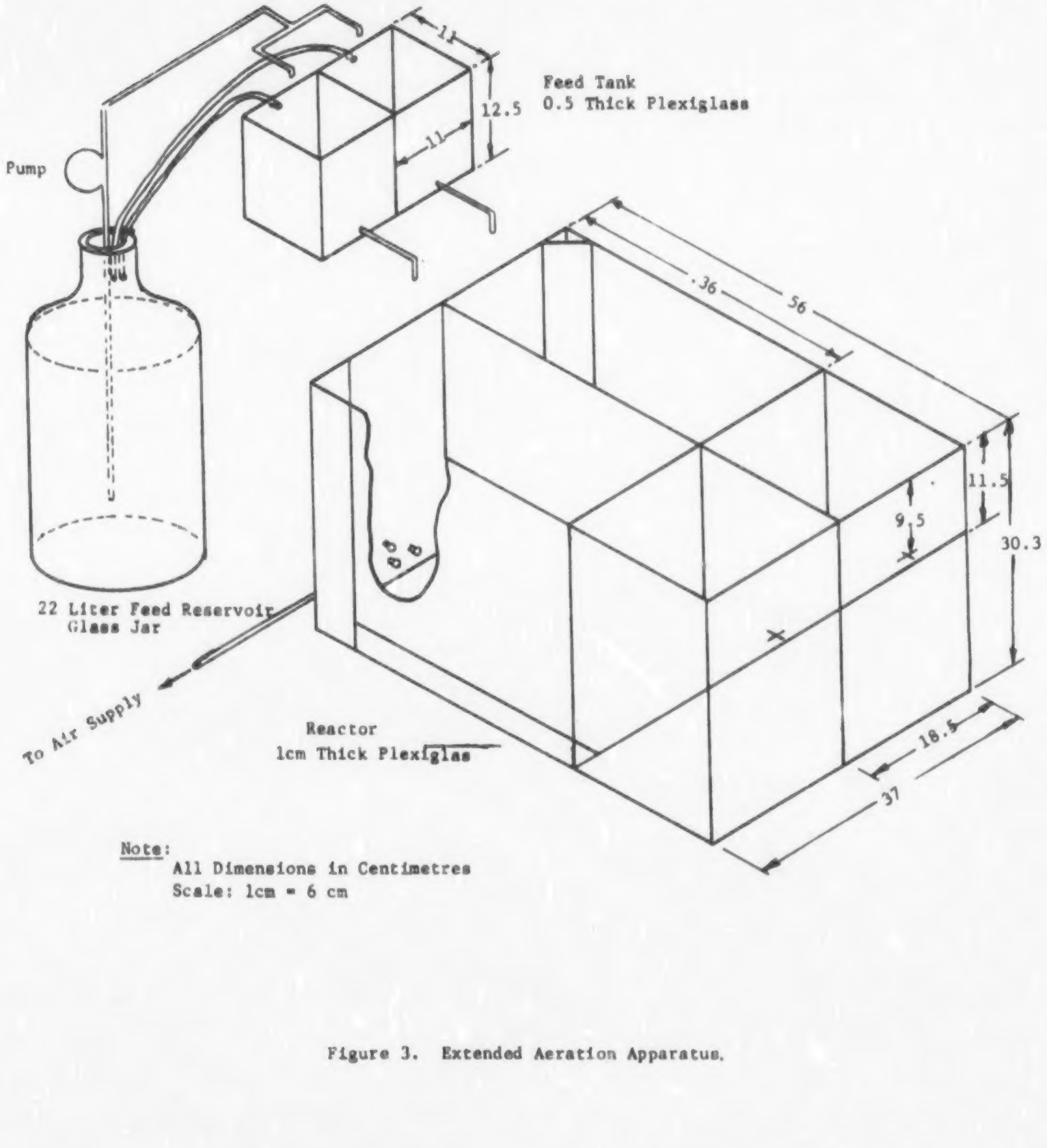
11
Feed Tank
0.5 Thick Plexiglass
12.5
11
Pump
36
56
11.5
9.5
30.3
22 Liter Feed Reservoir
Glass Jar
To Air Supply
Reactor
1cm Thick Plexiglas
18.5
37
Note:
All Dimensions in Centimetres
Scale: 1cm = 6 cm

Figure 3. Extended Aeration Apparatus.

TABLE 1. WASTEWATER CHARACTERISTICS

Characteristics	Unit	Sampling Points SP1	Sampling Points SP2	Sampling Points SP3
BOD$_5$	mg/ℓ			
Filtrate		303	76	257
Total		845	380	738
COD	mg/ℓ			
Filtrate		1000	300	755
Total		3013	1184	2147
Total Phosphate	mg/ℓ as P	4.88	5.31	5.49
Kjeldahl Nitrogen	mg/ℓ as N	60.0	24.5	20.0
BOD_F/BOD_T		0.36	0.20	0.35
COD_F/COD_T		0.40	0.25	0.35
BOD_F/COD_F		0.25	0.25	0.34
BOD_T/COD_T		0.28	0.32	0.34
BOD_T:N:P		173:12:1	72:5:1	134:3:1
BOD_F:N:P		61:12:1	15:5:1	43:3:1
Suspended Solids (SS)	mg/ℓ	640	185	1000
Volatile SS	mg/ℓ	590	150	880
Temperature	°C	30.0	28.0	38.0
pH		7.0	7.0	7.2
Grease	mg/ℓ	3700	3500	-
Flow Rate	m^3/day		1.24 ± 0.17	

BOD, COD, Nitrogen, Phosphorus, Temperature and pH values are 50 percentile probability levels.

1975, a central drainage system in the factory channeled all factory wastewaters to the discharge point SP1. The characteristics of the combined wastewater at SP1 were considered representative of the future discharge and this was used in subsequent treatability studies.

Table 1 presents 50 percentile probability values of wastewater characteristics. The BOD_5 to COD ratios of the wastewater are lower than expected for a food industry waste (usually about 0.5), probably due to the poor degradability of the grease in the analysis of BOD_5. Other characteristics of the waste, such as temperature, pH, and nutrient (nitrogen and phosphorus) concentrations are found to be optimal for the growth of microorganisms which is necessary for the functioning of biological treatment processes.

2. Wastewater Treatment Studies

2-1. Sedimentation/Flotation Process - The sedimentation/flotation process was studied for removal of suspended solids, COD, and grease. In Figures 4 and 5, they can be seen that total COD and suspended solid removal are less than 35% and 58% respectively with the time and depth of column applied in the present study. Since the higher percentage of volatile portion (about 92.2%) presented in suspended solid (Table 1), the removal of suspended solid by using sedimentation process become unnecessary. However, grease could be removed by the sedimentaiton/flotation process, as shown in Figure 6. It can be seen that if 1.25 m depth of tank is provided, it takes only 2 hours to achieve 90% grease removal by flotation.

2-2. Chemical Coagulation Process - The purpose of this study was to optimize the coagulating chemical dosage and pH so that maximum total COD and grease removal could be achieved. A summary of the results is given in Table 2. It can be seen that removals of 57-61 percent COD and 3.7-14 percent grease are possible using chemical coagulation. Optimal conditions are 80 mg/ℓ of alum dosage and pH of 6.5. However, using these conditions, the quality of the effluent from chemical coagulation still cannot meet the effluent standards set by the Ministry of Industry of Thailand.

2-3. Biological Treatment Process - Batch and continuous-flow system studies were carried out to investigate the BOD_5 and COD removal efficiencies of biological treatment processes since both physical and chemical methods were not found to be able to remove oxygen demand materials (BOD_5 or COD) to the required levels to meet the effluent standards.

The results of batch studies on the factory wastewater with and without grease skimming are shown in Figures 7 and 8. In general, the removal efficiency of BOD_5 (filtrate) and COD (Filtrate) are within the ranges of 96-97 percent and 84-93 percent, respectively. Residual BOD_5 contents in this study range from 7.5 to 20 mg/ℓ, which meet the required effluent standards (< 20 mg/ℓ). The effect of the presence of grease in the wastewater on the BOD_5 or COD removal efficiency of the batch activated sludge process is found to be negligible.

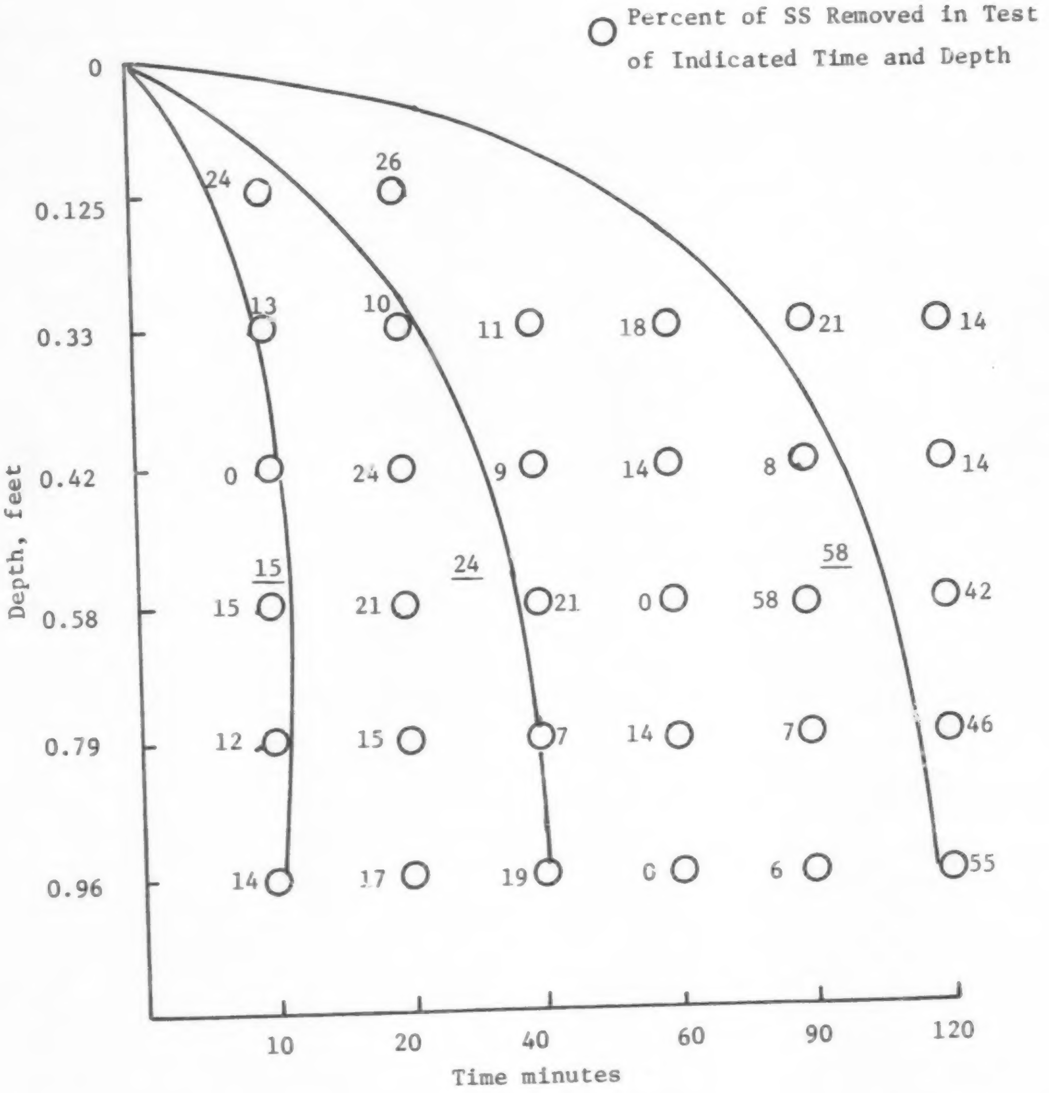

Figure 4. Suspended Solids Removal vs Time and Depth.

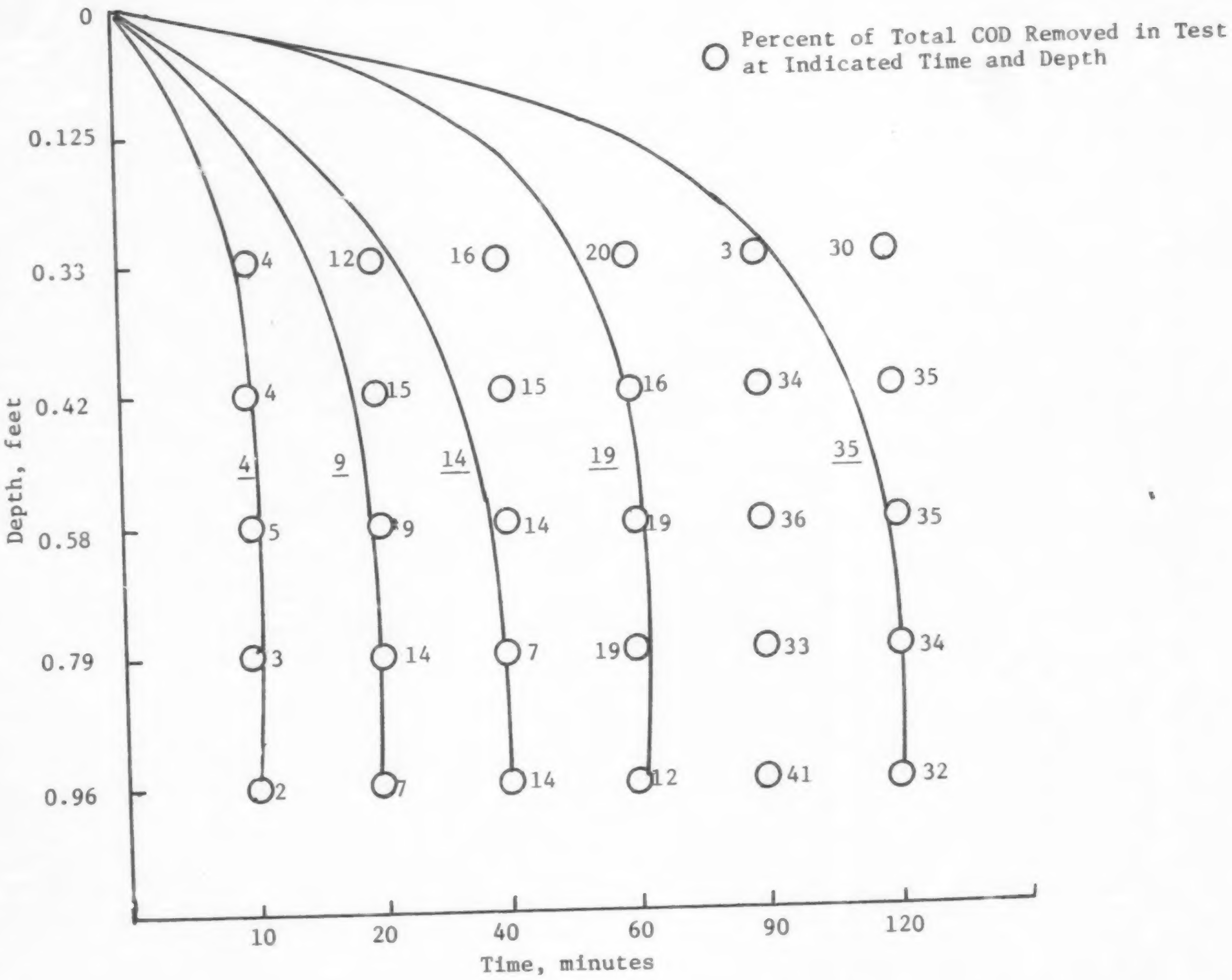

Figure 5. Total COD Removal vs Time and Depth.

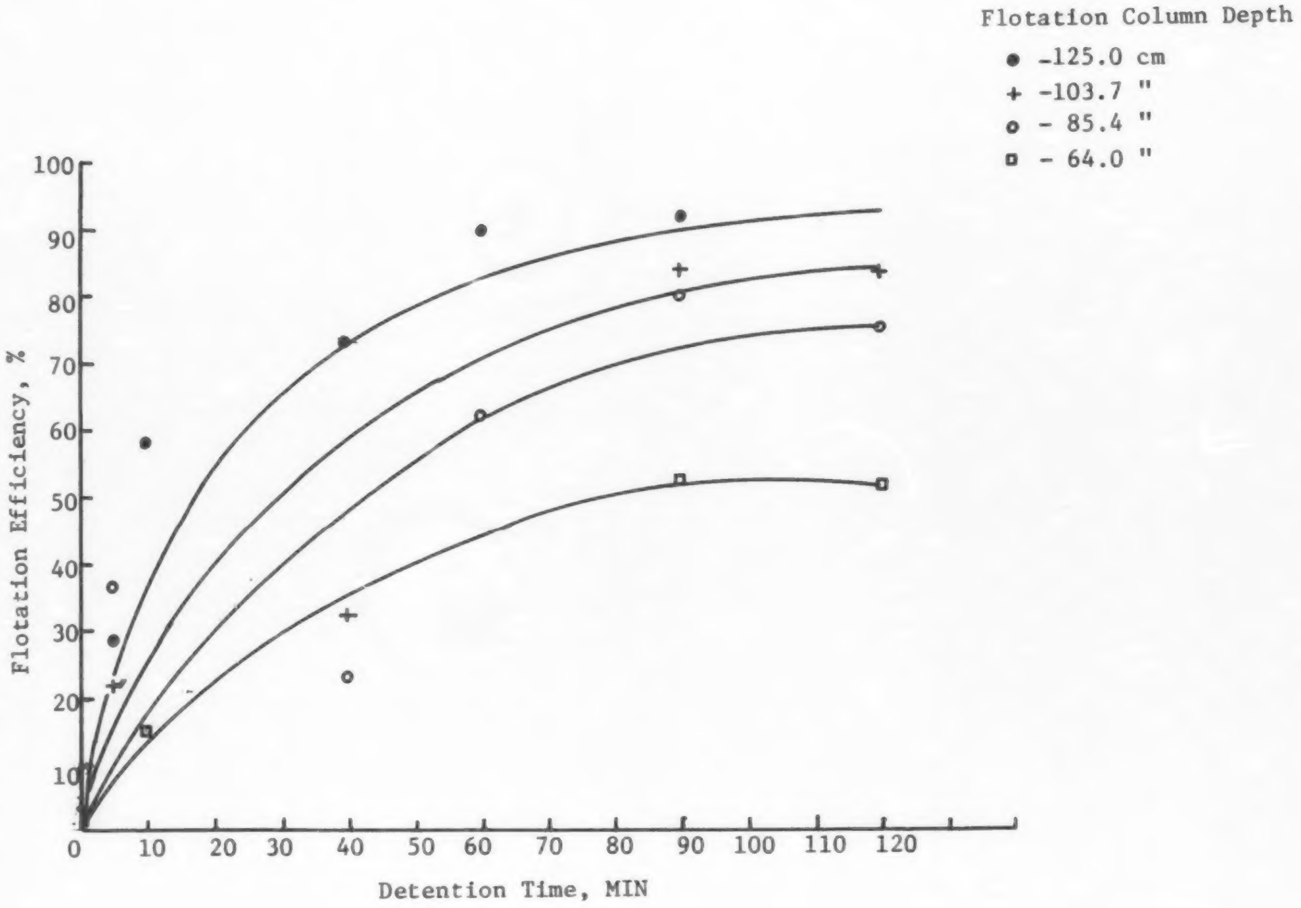

Figure 6. Grease Flotation Efficiency as Influenced by Detention Time.

TABLE 2. COAGULATION STUDY

I. Sample Characteristics:

pH = 6.66
Turbidity = 38.5 FTU
COD$_T$ = 1247 mg/ℓ
Grease = 267 mg/ℓ

II. Determination of Optimum Dosage:

	Alum Dose, mg/ℓ					
	20	40	60	80	100	120
pH	7.02	6.98	6.98	6.92	6.89	6.84
Turbidity (FTU)	37.0	36.0	33.5	23.0	16.0	9.0
Alkalinity (mg/ℓ)	510	460	450	440	410	430
Color	Dull	→	→	→	→	Clear
COD$_T$ (mg/ℓ)	415	415	405	324	405	283
Opt. Dose				↑		

III. Determination of Optimum pH at Optimum Dosage of 80 mg/ℓ Alum:

	pH					
	5.5	6.0	6.5	7.0	7.5	8.0
Turbidity (FTU)	7.0	7.5	17.5	33	40	38.5
pH	5.35	5.89	6.45	7.09	7.18	7.39
Color	Clear	→	→	→	→	greyish
Opt. pH			↑			

IV. Grease and COD$_T$ Removal at Optimum pH and Dosage:

	Optimum Dosage and pH				
	1	2	3	4	Untreated Sample
Turbidity (FTU)	27	27	32	25	33
pH	6.79	6.84	6.91	6.9	6.59
COD$_T$ (mg/ℓ)	487	555	536	526	1247
% COD$_T$ Removed	61	55.5	57	57.8	
Grease (mg/ℓ)	238	257	242	230	267
% Grease Removed	10.8	3.7	9.3	14	

1 and 2 adjusted to pH 6.5; 3 and 4 unadjusted pH.

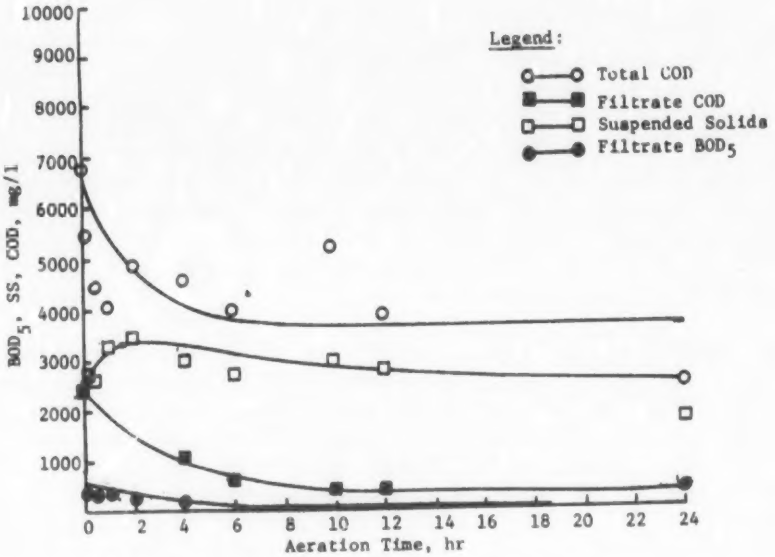

Figure 7. Batch Biological Process Without Grease Skimming Wastewater

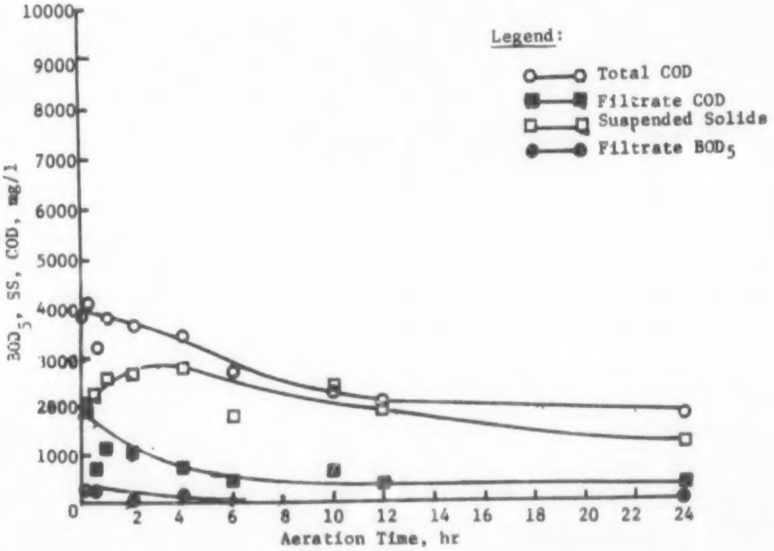

Figure 8. Batch Biological Process With Grease Skimming Wastewater.

Based on the wastewater characteristics and batch activated sludge studies, the extended aeration activated sludge process was selected for further study which could be possible for future practical application. By applying averaged organic loading rate of 0.413 and 0.23 of Kg Total BOD_5/KgVSS-day and Filtrate BOD_5/KgVSS-day, the BOD_5 removal efficiency was always above 90% and the BOD_5 content of the effluent was consistently lower than 20 mg/ℓ. However, the suspended solid concentration in the effluent was generally higher (160-300 mg/ℓ) than the effluent standard of the Ministry of Industry (less than 60 mg/ℓ). The loss of suspended solids in the effluent would be that the grease accumulated on the sludge. In the present study, it was also observed that the range of grease removal was varied from 3% to 54%. Apparently, the removal of grease becomes necessary before further biological process is proceeded. Certainly, it will improve the effluent quality based on the suspended solid concentration.

For further studies of biological treatment processes (including extended aeration, low-rate trickling filter, rotary tube filter and anaerobic contact processes) by using the same wastewater employed in the present study, Luis (2) concluded that the order at which high COD removal was observed was extended aeration > rotary tube filter > trickling filter > anaerobic contact process within the range of organic loading of 0.3882 to 0.9705 Kg COD/m^3-day as shown in Figure 9. Also, it was concluded that the order of overall performance for grease removal was trickling filter > rotary tube filter > anaerobic contact > extended aeration process as shown in Figure 10. Both rotary tube and trickling filters exhibited higher grease removals which may be that the slime (fixed film) is able to "adsorb" the grease from wastewater and which is finally slowly degraded. Relatively, the trickling filter shows a higher grease removal than the rotary tube filter because the specific surface area of the medium (corrugated PVC) used in the trickling filter is 195 m^2/m^3 compared to 76.4 m^2/m^3 for rotary tube filter.

RECOMMENDATIONS AND SUMMARY

1. The results of the studies suggest grease should be removed from the wastewater before other treatment processes are applied. This can be done by providing a grease separator as first stage in the process or, if batch or semi-continuous flow treatment is preferred, by arranging for surface skimming of grease from a holding tank.

2. Since the quantity of wastewater is very small, averaging 1.24 m^3/day, and the plant operates and produces wastewater only 8 hours per day, semi-continuos flow operation of a treatment plant is possible.

3. Raw wastewater sedimentation, even with chemical coagulation, is not recommended.

4. Biological treatment is necessary because of the high BOD_5, COD and volatile solids contents of the factory wastewater.

5. Considering the low flow and high grease content of wastewater, the extended aeration activated sludge process incorporating with prior removal of grease is recommended as most suitable for this wastewater.

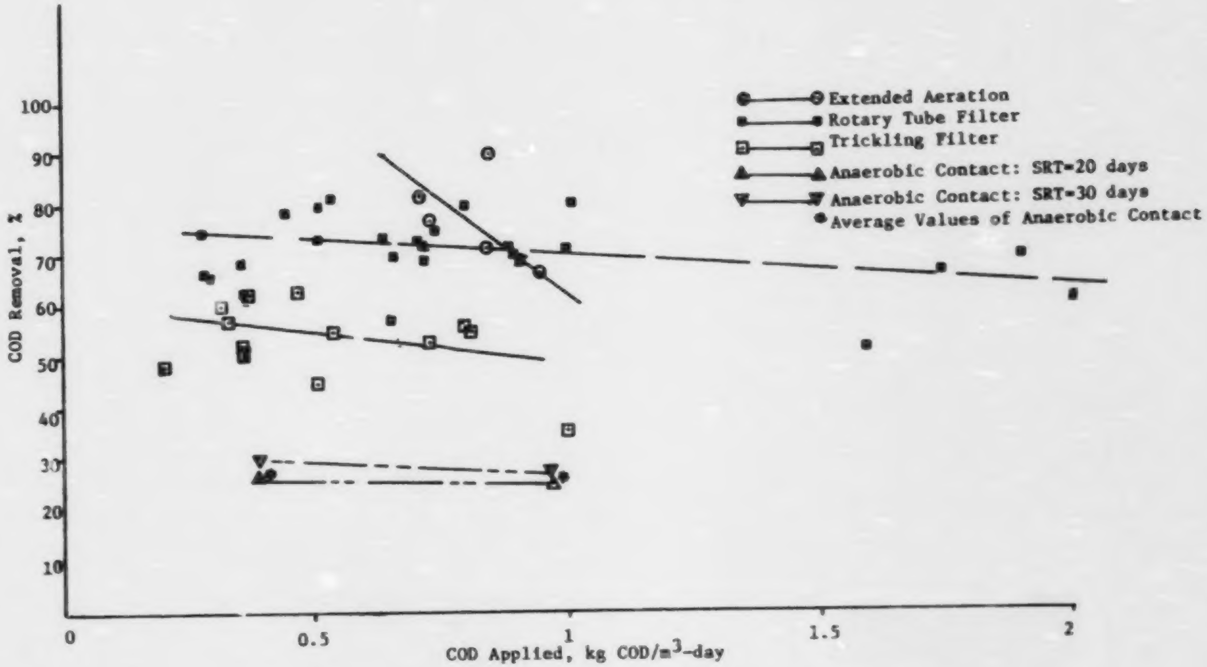

Figure 9. Comparison of COD Removal Efficiency of the Biological Process with COD Applied.

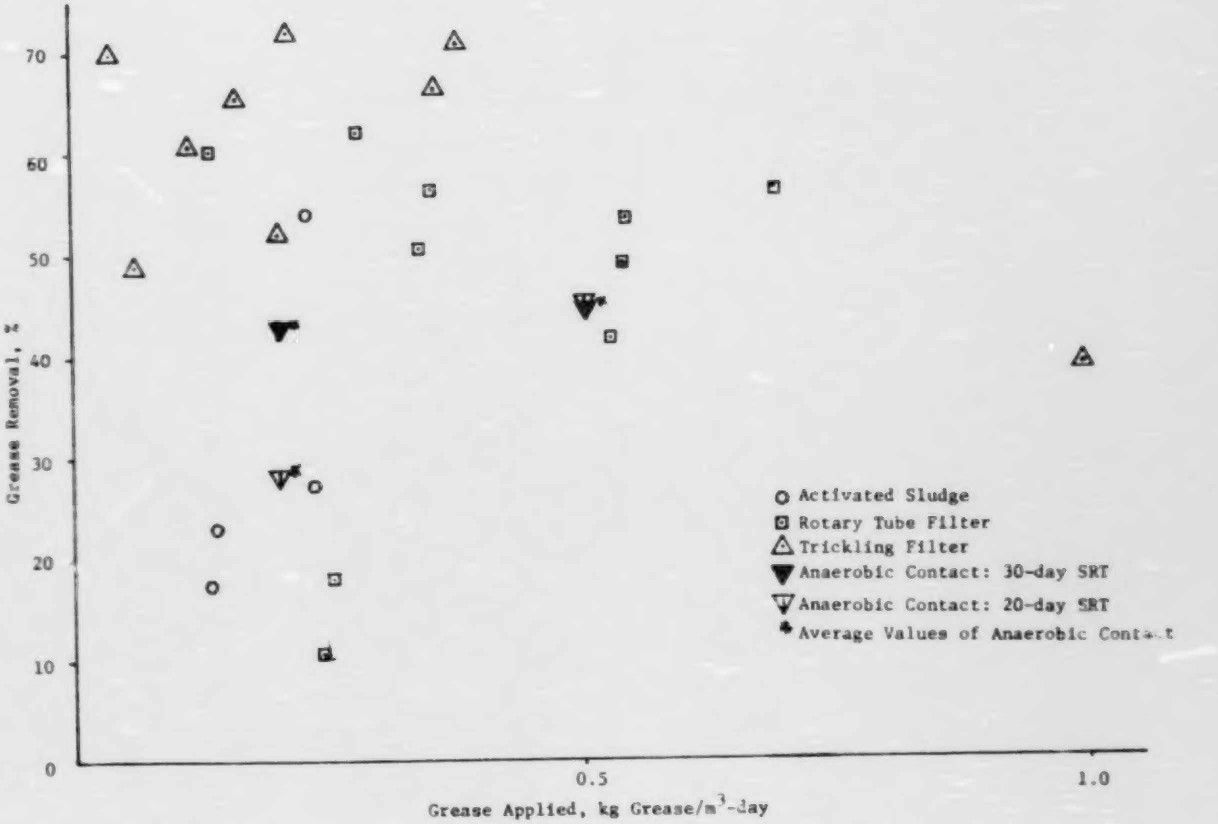

Figure 10. Comparison of Grease Removal Efficiency of the Biological Process with Grease Applied.

6. Either a semi-continuous or continuous flow activated sludge process would be appropriate forms of biological treatment.

7. The semi-continuous flow extended aeration process with grease skimming is outlined in Figure 11. This form of operational process would cost less in terms of construction cost but would involve more operational attention than a continuous flow process.

8. The continuous flow process alternative is outlined in Figure 12. This process would operate continuously with intermittent removal of grease from the holding tank and occasional removal of excess sludge from the activated sludge aeration tank. The sedimentation tank should be an integral part of the aeration tank, with the settled sludge returning by gravity to the aeration compartment.

At the present time, the factory has been treating its wastewater with the semi-continuous flow operation process and giving a satisfactory result. The present treatment facility was constructed by two times the figure recommended because the factory processing plant was expanded two times the original plant.

ACKNOWLEDGMENT

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REFERENCES

1. STANDARD METHODS FOR THE EXAMINATION OF WASTES AND WASTEWATER. 13th Ed., Amer. Pub. Health Assn., New York (1971).

2. Luis, Victor S. Biological treatment of noodle wastewater. Masters Thesis, Asian Institute of Technology, Bangkok, Thailand, No. 981 (1976).

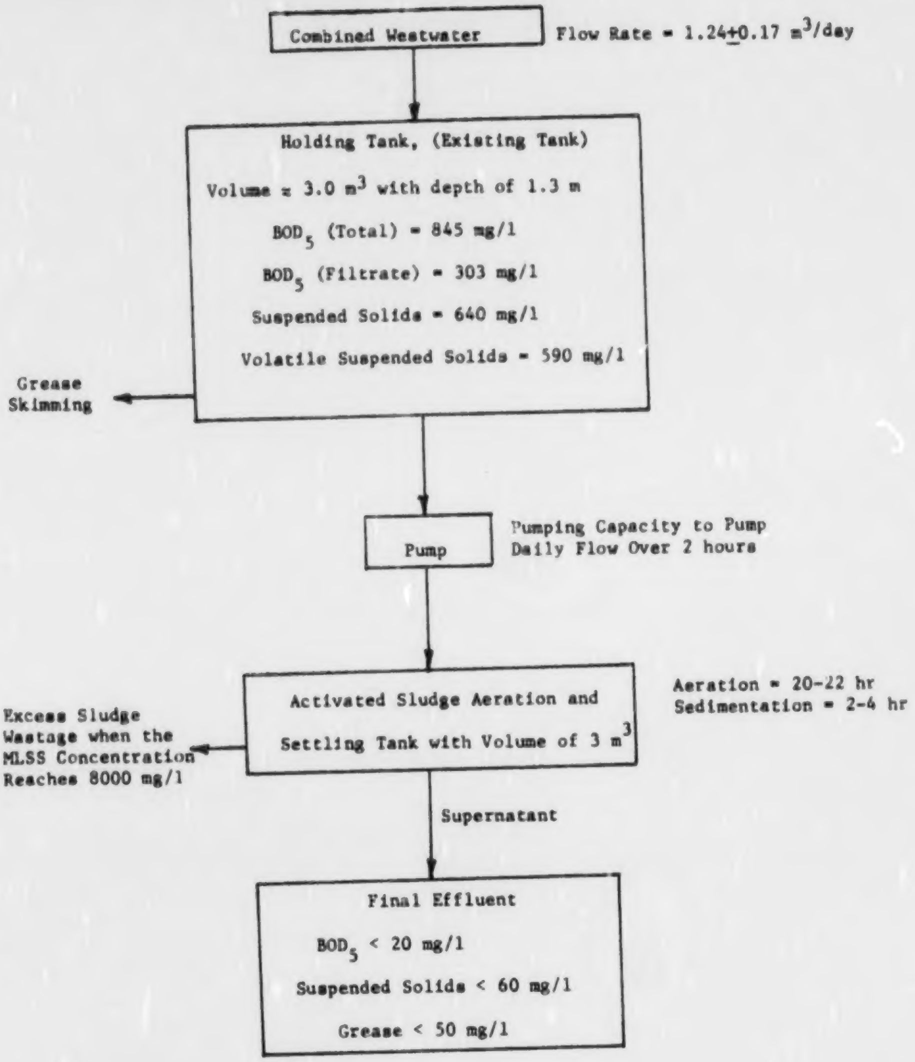
Combined Wastwater
Flow Rate = 1.24±0.17 m³/day
Holding Tank, (Existing Tank)
Volume ≈ 3.0 m³ with depth of 1.3 m
BOD₅ (Total) = 845 mg/l
BOD₅ (Filtrate) = 303 mg/l
Suspended Solids = 640 mg/l
Volatile Suspended Solids = 590 mg/l
Grease Skimming
Pump
Pumping Capacity to Pump Daily Flow Over 2 hours
Activated Sludge Aeration and Settling Tank with Volume of 3 m³
Aeration = 20-22 hr
Sedimentation = 2-4 hr
Excess Sludge Wastage when the MLSS Concentration Reaches 8000 mg/l
Supernatant
Final Effluent
BOD₅ < 20 mg/l
Suspended Solids < 60 mg/l
Grease < 50 mg/l

Figure 11. Recommendation of Semi-Continuous Flow Treatment Process.

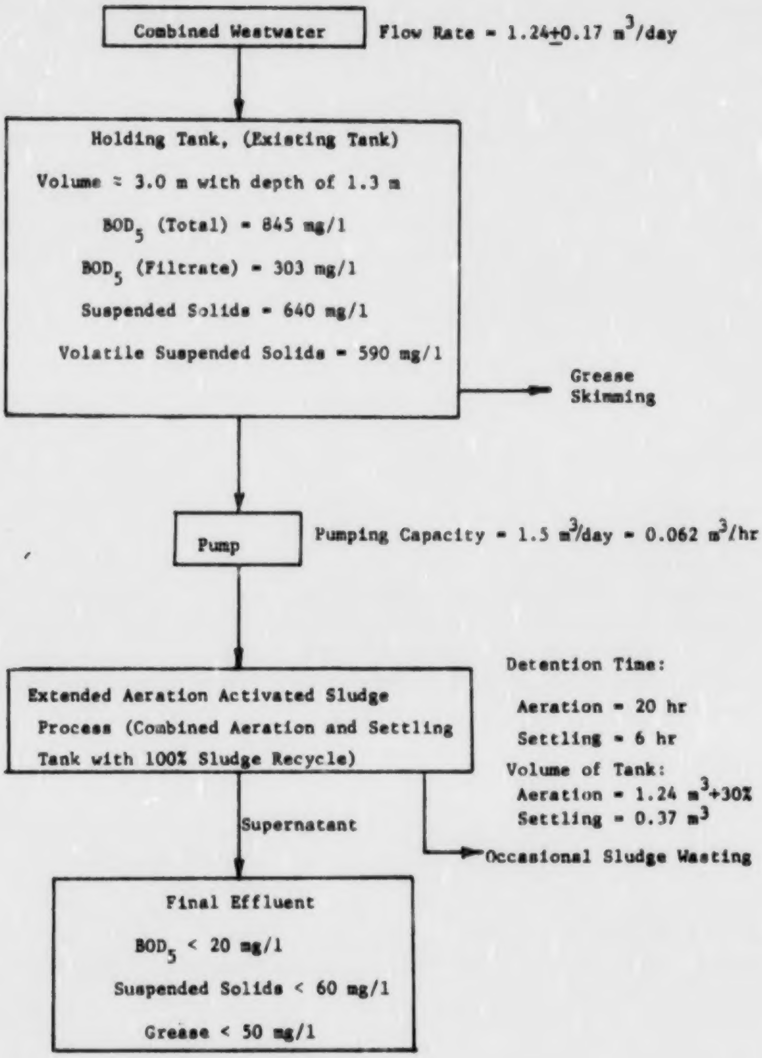
Combined Westwater
Flow Rate = 1.24±0.17 m^3/day
Holding Tank, (Existing Tank)
Volume ≈ 3.0 m with depth of 1.3 m
BOD$_5$ (Total) = 845 mg/l
BOD$_5$ (Filtrate) = 303 mg/l
Suspended Solids = 640 mg/l
Volatile Suspended Solids = 590 mg/l
Grease Skimming
Pump
Pumping Capacity = 1.5 m^3/day = 0.062 m^3/hr
Extended Aeration Activated Sludge Process (Combined Aeration and Settling Tank with 100% Sludge Recycle)
Detention Time:
Aeration = 20 hr
Settling = 6 hr
Volume of Tank:
Aeration = 1.24 m^3+30%
Settling = 0.37 m^3
Supernatant
Occasional Sludge Wasting
Final Effluent
BOD$_5$ < 20 mg/l
Suspended Solids < 60 mg/l
Grease < 50 mg/l

Figure 12. Recommendation of Continuous Flow Treatment Process.

POTATO JUICE PROCESSING*

by

J. R. Rosenau, L. F. Whitney, and J. R. Haight**

ABSTRACT

Various options are available for processing of potato juice into animal feeds. These include reverse osmosis, ultrafiltration, heat and acid coagulation of protein, vacuum evaporation, drum or spray drying, and acid solubilization and alkaline precipitation of solanine. The most promising flowchart is discussed in light of economics, solanine toxicity, lysine availability, trypsin inhibiter inactivation, and product characteristics.

INTRODUCTION

Traditionally, potato starch processes have involved grinding cull potatoes followed by sieving and refining operations which used large amounts of water (1) (2) (3) (4) (5). The water was used to separate the starch from the pulp and to refine, i.e., wash, this starch to a high degree of purity.

At the Seventh National Symposium on Food Processing Wastes, we presented a process (6) that reduced water usage, which has been as high as 1000 pounds per cwt. of input potatoes, to 25 pounds of water per cwt. We have since tuned and modified that process (see Figure 1) to eliminate an air classification step. The starch processing system (discussed in the following section since it affects options available to juice processing) produces a juice stream of about 5% solids. This paper summarizes factors influencing possible processing schemes for the juice.

STARCH PRODUCTION PROCESS

Figure 1 depicts the current modified starch production process. Potatoes are ground by hammer milling and the slurry wetsieved with recycled juice. The pulp remains above the 140 mesh screen while juice and starch pass through. The slurry is pumped to a liquid cyclone wherein the starch is spun to the underflow while the overflow is largely recycled to the screen. Excess juice at 5% total solids (w.b.) passes to the juice processing

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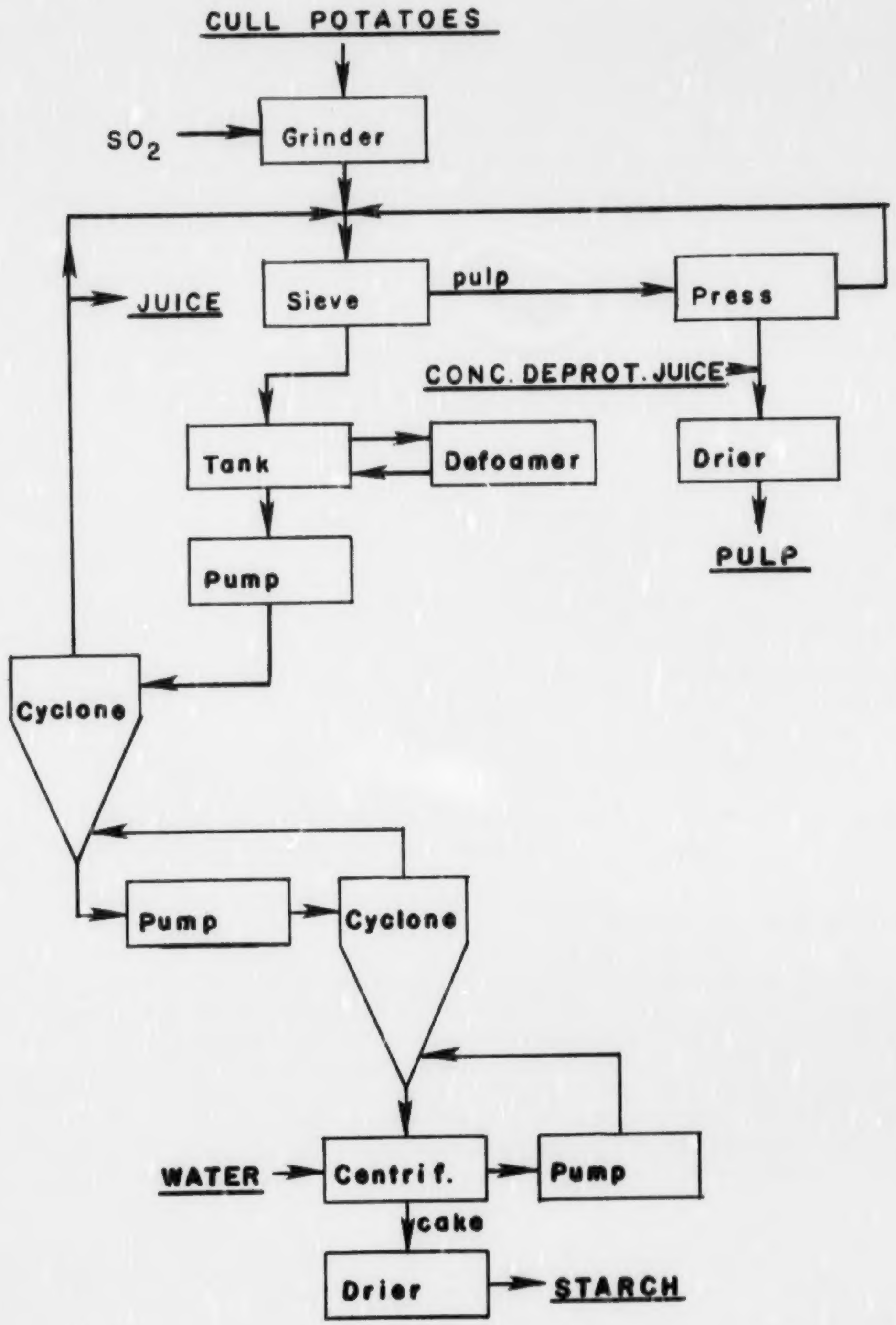
CULL POTATOES
SO_2
Grinder
Sieve
pulp
Press
JUICE
CONC. DEPROT. JUICE
Tank
Defoamer
Drier
PULP
Pump
Cyclone
Pump
Cyclone
WATER
Centrif.
Pump
cake
Drier
STARCH

Fig I. Starch and Pulp Processing Flowchart.

system. A defoaming device such as the Cornell Machine Company's* "Vesator" can be used as shown to control foaming - a problem of major importance if frozen or especially off-grade tubers are to be processed. The underflow from the liquid cyclone is pumped to a second liquid cyclone. The overflow from the second liquid cyclone is recycled to the tangential elutriation inlet of the first liquid cyclone (the design is a patented feature of the Bird Machine Company**). The underflow from the second cyclone passes to the basket centrifuge for final purification. Wash water in the amount of only 25 pounds for every 100 pounds of potatoes processed is introduced at this point. All of the liquid spun from the starch in the centrifuge is recycled to the liquid cyclone system.

The second liquid cyclone as shown, overcomes the problem of incomplete starch removal from the juice by a single liquid cyclone if the flow rates to the device are not very carefully tuned.

Centrifuged starch (60-65% T.S. (w.b.)) is dried - preferably in a flash drier to obtain maximum whiteness. Reflectance values in the range of 93.5-96% are obtained, however, even with simple tray drying at 60C. The crude protein content is about 0.06%. Air classification as previously used is unnecessary in the revised process.

ULTRAFILTRATION

The first obvious system for processing juice would include ultrafiltration to concentrate a protein stream in a similar manner to the now widely used system for cheese whey. Unfortunately, however, potato proteins, like soybean proteins, contain trypsin inhibitors which must be inactivated with heat. With little more heat than required for inactivation, the proteins are coagulated such that they can be collected and dewatered to 20% solids by centrifugation. It thus seems pointless to include a superfluous ultrafiltration step.

WHOLE JUICE CONCENTRATION

Juice can be concentrated by evaporation (with or without a reverse osmosis preconcentration step) and spray or drum dried to produce 50% crude protein meal. The Eastern Regional Research Laboratory of the USDA (ERRL) has recently investigated this option at some length (7). The dried juice is very hygroscopic unless lime is added before the drying step. Sufficient heating again must be done to inactivate the trypsin inhibitor. Chick feeding trials performed by R. Gerry at the University of Maine have shown that inclusion of this material at levels above 6% of the diet slow growth rates.

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*Cornell Machine Company, 45 Brown Avenue, Springfield, NJ 07081.
**Bird Machine Company, Inc., South Walpole, MA 02071.

E. O. Strolle (ERRL), in attempting to pinpoint the cause of this poor performance, has noted up to 80% losses in available lysine, apparently due to simple Maillaird browning, at evaporation temperatures as low as 60C (140F) (7). Armed with only the above facts, one would conclude that potato juice is only good for ruminant feeding. However, E. O. Strolle, in earlier trials, has conducted rat feeding trials with potato protein obtained by very rapid heat and acid precipitation followed by filtration and drum drying and has obtained PER's equal to casein. This suggests that the protein can be made to coagulate fast enough into a form wherein browning is inhibited. Braverman's text on food chemistry (8) supports the idea that reaction rates are very slow with materials not in solution. Moreover, acidic conditions also tend to slow browning reactions. This suggests a third general approach to juice processing.

HEAT PRECIPITATION

By rapid (i.e., by steam injection or infusion) heat and acid precipitation, potato juice proteins can be coagulated, centrifuged to roughly 20% solids, and dried (9) (10) (11). While the approach only collects about 35% of the crude protein of the juice, it yields a protein that is nonhygroscopic, concentrated (i.e., about 70% protein (d.b.)), and without antitrypsin activity. The 35% figure includes nearly all the TCA precipitable protein. The rat feeding tests mentioned above suggest that the protein is well balanced. The deproteinated juice can be concentrated (with or without reverse osmosis preconcentration) to 70% solids without serious foaming problems. Since there is no way to prevent lysine destruction with this material, the obvious way to dispose of it is to add it back to the pulp (which serves as a drying aid) and dry it for ruminant feeding. (Ruminants do not require a balanced protein.) Where feed lots are in close proximity to the factory, this drying step can be eliminated. A final question with respect to the heat coagulation process (see Figure 2) is the distribution of glycoalkaloids naturally occurring in cull potatoes.

SOLANINE

Solanine is the principal component of the toxic glycoalkaloids found in potatoes. (The word "solanine" is also used to denote the whole family of these materials (12) (13).) Dutch researches (14) have suggested that up to half of the solanine is associated with heat coagulated protein. Our recent results with juice heated at pH 4 do not confirm this. Rather, the solanine seems to act as if it were soluble and can be found in the various output streams in rough proportion to the water content of these streams at the point of separation. In particular, the solanine content of heat and acid precipitated protein is about the same, on a dry-weight basis, as the parent potatoes. The deproteinated juice is rich in solanine but by blending this fraction with the pulp, the solanine is diluted. The resulting pulp mixture contains about twice the solanine content (again on a dry-weight basis) of the parent potatoes. T. J. Fitzpatrick and S. F. Osman (ERRL), who have worked extensively with solanine, feel that, at this level, solanine should not pose a problem with feeding of the pulp to ruminants which are the only animals that can utilize it. This is a reversal from the viewpoint

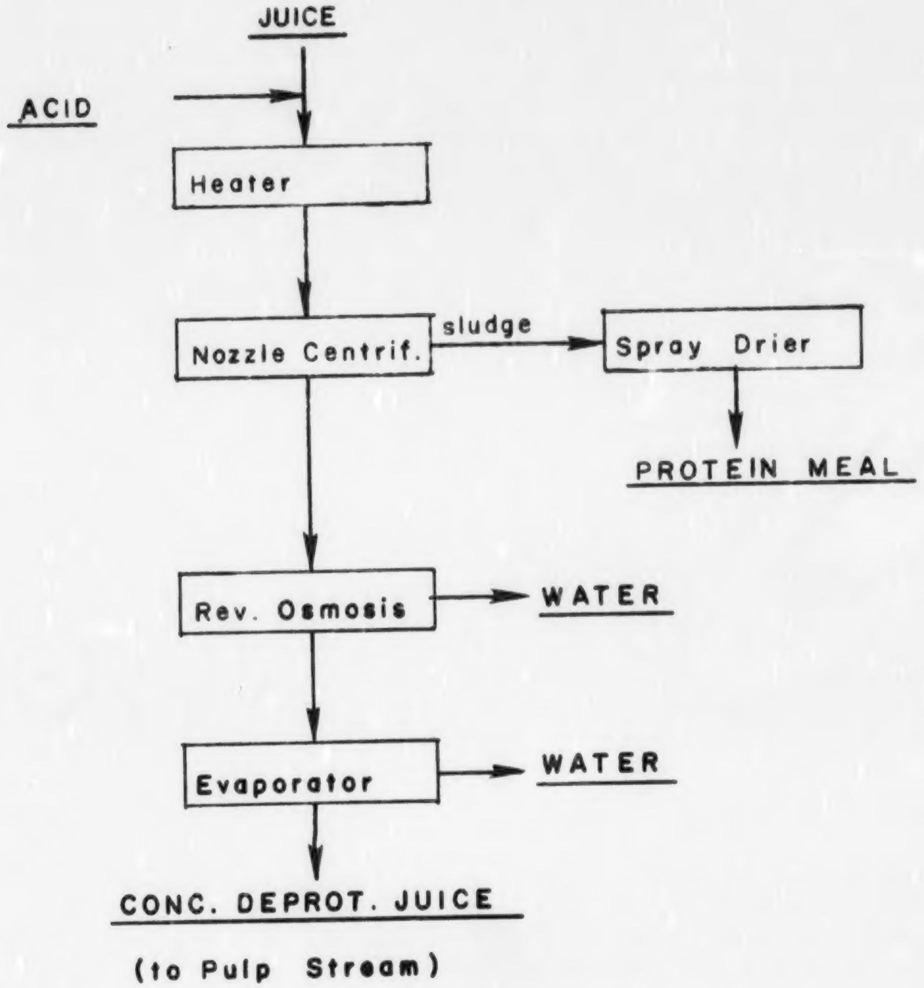
JUICE
ACID
Heater
Nozzle Centrif.
sludge
Spray Drier
PROTEIN MEAL
Rev. Osmosis
WATER
Evaporator
WATER
CONC. DEPROT. JUICE
(to Pulp Stream)

Fig. 2. Juice Processing Flowchart.

that solanine would have to be solubilized by acid extraction and then precipitated and removed by raising the pH followed by centrifugation with a disk type automatic desludging centrifuge.

FOAMING

Potato juice has a great tendency to foam. Juice from partially frozen potatoes is especially troublesome. Defoaming chemicals, if used in sufficient quality, can control the problem but are expensive.

The Cornell Machine Company "Versator" has been used under plant conditions and has proven effective in breaking foam. The machine is based on the principle of sheeting the foam onto a spinning curved disk within a vacuum chamber. The defoamed liquid, of course, maintains its foaming characteristics and, if again agitated with air, will refoam. The "Versator" is of no use in handling foaming problems during evaporative concentration.

An ultrasonic probe was tested to see if high energy sound could be used to break up the foam but the results were totally negative.

Heating to the point of coagulation greatly reduces the foam stabilization properties of the protein. Juice treated in this manner can be evaporated without serious foaming problems.

YEAST FERMENTATION

The last remaining starch plant in the Northeast has installed, in a cooperative venture with Bio-kinetics, Inc.*, a yeast fermentation system. They are experiencing some start-up problems with foaming since they are aerating, in open tanks, whole juice without heat treatment.

An additional problem with fermentation systems is that starch plants use high levels of SO_2 to overcome enzymatic browning. We feel that these levels pose problems for any single cell process unless it is precipitated or stripped.

PRELIMINARY ECONOMICS

The present economic picture remains satisfactory although the current depressed price of cornstarch is not helpful. One hundred pounds of incoming potatoes should produce 12.2 pounds of 18% moisture starch which, at 11¢ per pound, yields $1.34; 1.1 pounds of protein meal (10% moisture) ($180/ton), $0.10; and 8.9 pounds of pulp (10% moisture) (100/ton), $0.45 for a total of $1.89.

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*Bio-kinetics, Inc., 914 Mission Avenue, San Rafael, CA 94901

It is difficult to place a value on cull potatoes. A recent Canadian publication mentions \$0.27 per cwt. In some seasons, this value might increase to \$2.00 per cwt. Current Maine prices are approximately \$0.75. Energy costs will be \$0.16 per cwt processed assuming $\$3.00/10^6$ Btu. This leaves a gross margin of \$0.93 per cwt processed if we assume miscellaneous supplies will be \$0.05 per cwt.

If we assume an average of 400 ton of potatoes are processed each day of a 200-day campaign, that we have a labor force of 10 persons with an average cost of \$20,000/year each, that the plant costs about \$2,000,000 and that 20% of this must be used per year to cover maintenance, taxes, depreciation, etc., we find a 42% R.O.I. Obviously a more detailed cost analysis must (and will be) be performed to confirm the economic feasibility of the processes presented.

SUMMARY

In light of the apparent retention of lysine availability in heat coagulated protein, its loss in soluble protein processing, the apparent solubility of solanine, and the reduction in foaming ability by heat coagulation, a logical juice processing scheme becomes obvious. Juice is heated quickly and centrifuges. The resulting protein sludge (roughly 20% solids, 70% crude protein (d.b.)), which accounts for about 35% of the crude juice protein, is spray dried as a high protein meal. The remaining juice is concentrated to 15% solids by reverse osmosis followed by evaporation to 70% solids. It is then mixed with the pulp for drying which acts as a carrier for the otherwise difficult to dry hygroscopic material.

REFERENCES

1. Hemfort, H., Huster, H. and Heimeier, 1975. Low water consumption in preparing potato starch. Reviewed by Peterson, N.B. Edible Starches and Starch-Derived Syrups. Noyes Data Corp., Park Ridge, NJ.

2. Hicks, C.P., 1970. Starch refining 2-quality, yields and equipment. Process Biochemistry 5 (7): 30.

3. Howerton, W.W. and Treadway, R.H., 1948. Manufacture of white potato starch. Industrial and Engr. Chem. 40(8): 1402.

4. Treadway, R.H., 1959. Potato starch. Potato Processing, ed. by Talburt, W.F. and Smith, O., AVI Publishing Co., Westport, CT.

5. Treadway, R.H., 1967. Manufacture of Potato Starch, ed. by Whisler, R. L. and Paschall, E.F., Starch: Chemistry and Technology Vol. II, Academic Press, NY.

6. Rosenau, J.R., Whitney, L.F. and Elizondo, 1976. Low wastewater potato starch/protein production process - concept, status, and outlook. Proceedings of the Seventh National Symposium on Food Processing Wastes.

7. Strolle, E.O., 1977. Verbal communication. Eastern Regional Research Laboratory, 600 East Mermaid Lane, Philadelphia, PA 19108.

8. Braverman, J.B.S., 1963. Introduction to the biochemistry of foods. Elsevie Publishing Company.

9. Anon., 1968. Protein. Protein recovery from potato starch, Process Biochemistry. May, 1968, p. 51.

10. Stabile, R.L., Turkot, V.A., and Aceto, N.C., 1971. Economic analysis of alternative methods for processing potato starch plant effluents, Proceedings of the Second National Symposium of Food Processing Wastes, Denver, CO.

11. Strolle, E.O., Cording, J., Jr., and Aceto, N.C., 1973. Recovering potato proteins by steam injection heating. J. Agr. Chem. 21 (6): 974.

12. Jadhav, S.J., and Salunkhe, D. K., 1975. Formation and control of chlorophyll and glycoalkaloids in tubers of Solanum tuberosum L. and evaluation of glycoalkaloid toxicity. Advances in Food Research, Vol. 21. ed. by Chichester, C.O. Academic Press, NY.

13. Alvarado, R., and Fagerson, I.S., 1976. Personal Communication. Dept. of Food Science and Nutrition, University of Massachusetts, Amherst, MA 01003.

14. deNoord, K.G. 1976. Personal communication. Avebe, P. O. Box 15, Veendam, Holland.

RECOVERY AND APPLICATION OF ORGANIC WASTES FROM THE LOUISIANA SHRIMP CANNING INDUSTRY

by

B. E. Perkins and S. P. Meyers*

INTRODUCTION

Since 1968, investigations from our laboratory have documented the value of "waste" proteinaceous substrates from Louisiana shrimp and crawfish processing industries(1) (2) (3). Overall efforts have been directed toward material recovery and development of a diversity of applications of proteinaceous byproducts. With regulatory requirements necessitating screening of solids from effluent discharges, shrimp canning operations are experiencing an abundance of solid waste materials. Efforts to upgrade the quality of meals from shrimp and other crustacean wastes are in progress, especially in terms of the effect of processing conditions on nutritional and pigment value. This is particularly important in view of the demonstrated variability in analyses and potential nutritional composition of shrimp meals(4). Further attention is being given to reduction of BOD loads of discharge streams and economically sound use of recovered proteinaceous material.

The magnitude of shrimp waste in the Gulf Coast area for recovery and application is by no means insignificant. The total heads-on landings for the Gulf Coast canned and frozen shrimp industry, including both brown and white shrimp, amounted to 179.5 million lbs in 1976. Based upon a loss of 75.9% of the heads-on weight, the total potential waste, including materials such as heads, shells, legs, etc., from both the Gulf canned and frozen shrimp industries is 136.3 million lbs (Fig. 1).

The calculated waste generated in the various effluent streams from the processing operations is noteworthy (Fig. 2). Based on an approximate 3.3 gal water/lb shrimp processed, as much as 600 million gal are used in shrimp processing in the Gulf. Included in this volume is a total potential dissolved and suspended microscopic waste load of 4.7 million lbs. Approximately 3.3 millions lbs dry wt (16.5 million lbs wet wt) of this waste is from the frozen, peeled tail operations, while the canning portion (raw and blanch wastes) contributed 1.4 million lbs dry wt (7.0 million lbs wet wt). In the main, recovery and use of this dissolved shrimp protein has been neglected with prime attention being given to macroscopic solids recovery as a meal substrate.

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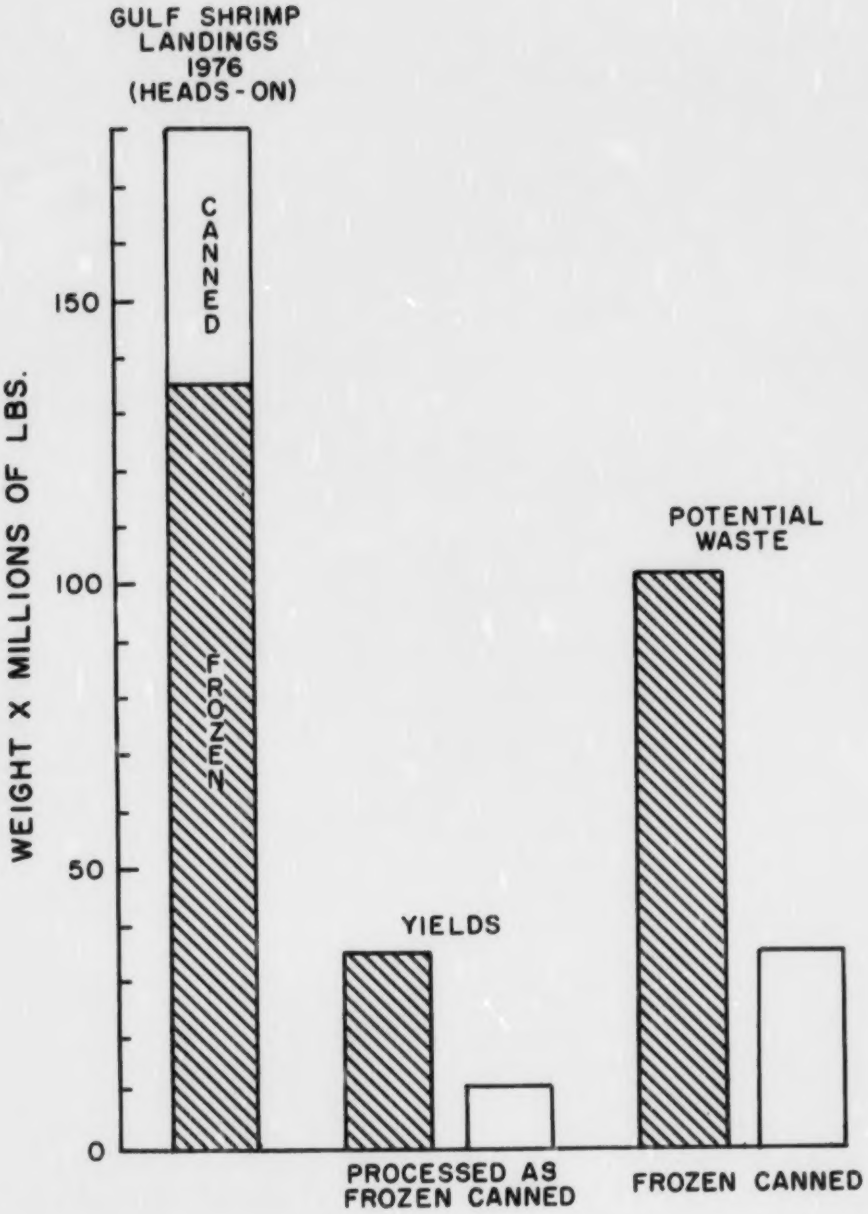

Figure 1. Gulf shrimp landings, yields and potential waste, 1976.

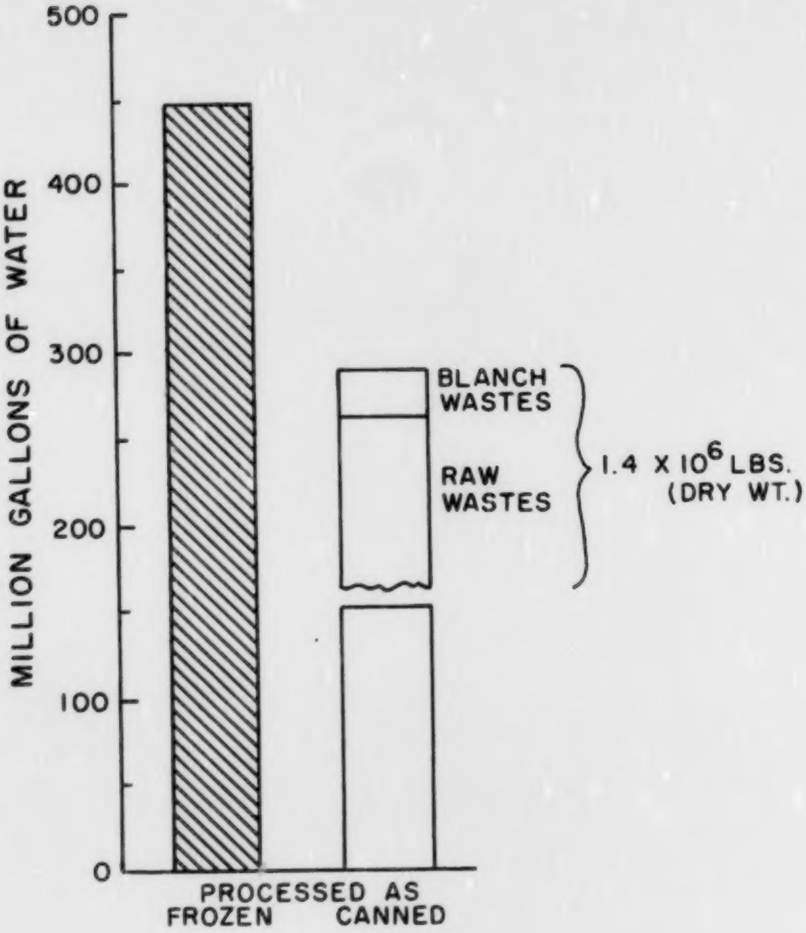

Figure 2. Amount of water used in Gulf Coast shrimp processing, 1976.

The general waste flow from shrimp canning involves largely three separate components: a) material from the peeling, separating and deveining operations; b) that from the blanch tanks; and c) the shrimp meat and debris during the several inspection phases. Primary attention has been given to the blanch portion of the process in terms of recoverable proteinaceous material from the hot brine liquor. Aspects considered in this study have included in-plant characteristics, notably ratio of blanch load to total discharge and to volume and meat/liquid ratio, load fluctuations and seasonal peak features; variations between plants, i.e., process flow, blanch time, salinity and temperature, and shrimp load and characteristics; analyses of potential biochemical/nutritional application of product in terms of facility logistics. Changes in dissolved organic and suspended meat levels as related to averages or trends in shrimp size also are important and must be tabulated in overall analyses of recovery variability.

Many facets of the shrimp canning operation have been presented in earlier reports(5) (6) directed toward development of an economical, practicable method of effectively and efficiently treating waste waters from such plants. Studies involved characterization of the BOD-5 and suspended solids, including that of the water flume dumps, canning, and retort cooling and inspection. It was calculated that the peeling operation contributed approximately 70% of the BOD-5 (4.89 lbs/100 lbs shrimp) and suspended solids (2.63 lbs/100 lbs shrimp) to the total discharge, compared with <5% for the blanching phase. Data generated in the previous and current studies will be used for evaluation and application in design, construction and operation of wastewater treatment systems for the shrimp canning industry, particularly on the Gulf Coast.

MATERIALS AND METHODS

Sampling Techniques

Samples of effluent streams were taken from three major shrimp canneries in Westwego and Harvey, in the greater New Orleans vicinity. More than 20 such facilities of various sizes are located in the Louisiana-Mississippi Gulf region, the majority of which are found in the New Orleans and Houma, Louisiana area. Logistics of areal plant concentrations are important in any projection of economics of by-product recovery and ultimate use.

Blanch water was taken directly from the blancher overflow valves. While a batch process was used in early stages of the industry, most plants now employ a continuous system in which shrimp are passed through the tank via a screw conveyor and brine water is continually added, with surplus washed from the tank. In blanching or pre-cooking operations(7) shrimp are processed in a boiling brine which extracts moisture and solubles, curls the meat, and develops the characteristic pink to red color of the final product. During this treatment, both particulate and dissolved shrimp protein is concentrated in the liquor which is discarded usually at the end of the daily processing. The three facilities studied all use continuous blanchers in which the greater portion of the water is recirculated within the tank and a lesser amount discarded through an overflow valve. As noted, overflow loss is compensated for by addition of fresh brine, procedures for which vary from plant to plant. Since processing equipment used in the three canneries sampled is more or less similar in operation, differences in by-product loading rates as a result of dissimilar equipment may be discounted.

Raw wastewater was collected from effluent streams carrying wastes from the washing, peeling, and deveining operations. All liquid material was collected and stored for transport in 5-gal plastic carboys. Samples of solid waste composed of detritus remaining after initial picking, bits of shell not removed during peeling, and broken pieces of cooked shrimp were also collected. Samples were collected from the discharge chute of the after-blanch air cleaner. All solid samples were packed in plastic bags and stored in ice chests. Subsequently, all material was transported to the LSU Department of Food Science at Baton Rouge and frozen at -5 C until analyzed.

Shrimp Blanch Water Analysis

Blanch water samples were filtered through cheesecloth to remove suspended meat fragments, dried in a microwave oven (Amana Touchmatic Radarange Model #RR-6-W), and the resulting dry weights recorded. Unless otherwise indicated, all dry weight determinations were made in this manner.

The protein liquor obtained after removal of suspended meat was adjusted to pH 4.2 via 12 M reagent-grade (37-38%) HCl, thus allowing for isoelectric precipitation of dissolved proteins. After precipitation was complete (60-75 min), the supernatant layer (sugar liquor) was removed and the precipitate centrifuged at 10,000 rpm for 10 min. The supernatant was added to the previously-siphoned sugar liquor. Dry weight of dissolved protein removed was determined.

The sugar liquor obtained after removal of dissolved protein was adjusted to pH 9.5 with technical-grade $Ca(OH)_2$. Adjustment to pH 9.5 in the presence of Ca^{++} ions permitted isoelectric precipitation and salting out of the dissolved sugar. Following this, the supernatant layer (final effluent) was siphoned and the precipitate centrifuged at 10,000 rpm for 10 min. The supernatant was added to the previously-siphoned final effluent. Dissolved sugar removed was dried and weighed.

To determine the amounts of dry solids in the unused blanch water (brine water) and the final effluent, samples of each were vacuum-dried at 85 C/30 in. Hg pressure.

Raw Shrimp Processing Water Analysis

Raw shrimp processing water was filtered through cheesecloth to remove suspended meat fragments and shells which were dried and weighed. The remaining protein liquor obtained was adjusted to pH 4.2 with 12 M HCl, permitting precipitation of dissolved proteins. The supernatant layer was siphoned and discarded, and the precipitate centrifuged at 10,000 rpm for 10 min and dried and weighed.

Determination of Total Carbon in Shrimp Blanch Water

Samples of each of the previously-dried components, i.e., dry material from fresh brine solution untreated blanch water, protein liquor, sugar liquor, and final effluent, were ground in a mortar and pestle and weighed in 0.1 g amounts. All of these were taken uniformly at 1 hr after start-up of process. Each sample was analyzed for total carbon with a Hoskins electric furnace (1000 C). Total carbon was converted to CO_2 gas, which was captured in an Ascarite-containing vessel. Changes in weight in the Ascarite-containing vessel indicated the weight of the CO_2 absorbed. From these values, total carbon contents of each of the components was calculated and recorded.

RESULTS AND DISCUSSION

Isoelectric Point Precipitation

Major attention has been given to isoelectric point precipitation with HCl and preliminary centrifugation, as well as use of specific coagulants such as chitosan (Hercules Co., Kytex H®). In initial tests (Table 1), concentrated H_2SO_4, concentrated HNO_3, and glacial acetic acid appeared to be good precipitating agents, although none were as effective as concentrated HCl.

TABLE 1. EFFECTIVENESS OF DIFFERENT ACIDS ON ISOELECTRIC POINT PRECIPITATION

Acid	Precipitated shrimp protein/gal[1]
Concentrated HCl	303 g
Concentrated H_2SO_4	152 g
Concentrated HNO_3	175 g
Concentrated CH_3COOH	230 g

[1] Precipitated within 2 hr.

Isoelectric precipitation of suspended and dissolved proteins is more rapid when fresh blanch water is used. Samples frozen and stored at -5 C for <2 wks also showed good precipitation. Those stored at -5 C in excess of 2 wks required additional levels of concentrated HCl for effective recovery of proteins. This may be due to molecular destruction caused by ice crystal formation or chemical modification under prolonged storage. Precipitation occurs more rapidly at low temperatures.

Addition of $Ca(OH)_2$ at concentrations of 2.5 g/L acidified blanch water reduced overall flocculation time by 50%, from several hours to less than one hour. Neither OH^- alone (added as NaOH) or Ca^{++} (added as $CaCl_2$, $Ca(No_3)_2$ or $CaHPO_4$) achieved a similar effect. In one test, using a 2% chitosan-acetic acid (100 ml of a 10% solution) mixture, flocculation of the blanch water was not observed, even at the isoelectric point of pH 4.2. Comparable results were obtained when varying amounts of $CaCl_2$, $Ca(NO_3)_2$, and $CaHPO_4$ were added to the chitosan-acetic acid blanch water mixture. However, supplementation with 0.5% $Ca(OH)_2$ resulted in excellent flocculation, comparable to that obtained with HCl and 0.5% $Ca(OH)_2$. Noteworthy differences in hardness and texture of the proteinaceous precipitate were seen with the various treatments.

The addition of calcium hydroxide or chitosan in conjunction with isoelectric point precipitation caused a change in the appearance of the precipitated protein. With increasing concentration of $Ca(OH)_2$, the sediment becomes somewhat harder or "cake-like," rather than the usual consistency, much like that of toothpaste. Chitosan, on the other hand, causes the sediment to become softer, with the consistency of mucus. It appears that $Ca(OH)_2$ is superior to chitosan as an additional clearing agent of the supernatant layer. Further testing is needed to see whether texture of the final product can be manipulated through use of agents such as $Ca(OH)_2$ or chitosan to suit a particular application. Additional evaluation of other acids and coagulants for protein precipitation is also worthwhile.

Dry Weight Determination--Shrimp Blanch Water

Dry weight determination of the various components or groups in shrimp blanch water represent averages from fifteen collections over the period May through December, 1976 (Table 2). This period includes samples of both the brown shrimp (*Penaeus aztecus*) and white shrimp (*Penaeus setiferus*).

TABLE 2. CHARACTERIZATION OF SHRIMP BLANCH WATER

	Average concentration (dry wt)	
Component	g/gal H_2O	lb/100 lb raw shrimp
Suspended meat fragments	9.5	0.11
Dissolved protein	33.5	0.39
Dissolved sugar	4.6	0.05
Other solids*	194.0	2.27
Total	241.6	2.82

*Includes salts, trace elements, miscellaneous organics.

Mauldin and Szabo(6) reported suspended solids in shrimp blanch water as much as 0.19 lb/100 lb raw shrimp processed. Currently, discounting that component noted as "other solids" (Table 2), total suspended and dissolved solids are 0.55 lb/100 lb raw shrimp processed. On a gallon basis, recoverable dissolved protein is 7.5% of the total. Both suspended meat fragments and dissolved protein are in sufficient amounts for economical recovery, and while the dissolved sugars are not present in large concentrations, their removal may be necessary to comply with pending EPA "zero discharge" regulations. It might be possible to accumulate the remaining sugar liquor following removal of the proteinaceous fractions, concentrate the dissolved solids, and remove these together.

Dry Weight Determination--Raw Shrimp Processing Water

Results obtained on the various portions of the raw shrimp processing water are averages from the same fifteen collections made for the shrimp blanch water (Table 3).

TABLE 3. CHARACTERIZATION OF RAW SHRIMP WASTEWATER*

Component	Average concentration (dry wt) g/gal H_2O	lb/100 lb raw shrimp
Dissolved protein	3.39	2.44
Shells, legs, heads	21.10	15.16
Total	24.49	17.60

*Includes peeling, washing, deveining, and miscellaneous uses.

Mauldin and Szabo(6) report suspended solid loads in raw wastewaters of 3.68 lb/100 lb raw shrimp processed. Table 3 shows an amount of total suspended and dissolved solids of 2.44 lb/100 lb raw shrimp processed. Grams of substrate/gal recovered, less solids, is approximately 50% of that found in the blanch water effluent. Applications for raw dissolved shrimp protein have not been fully investigated. Possibly, the nutritive value of the extracted raw protein is superior to that of the material extracted from the blanch tanks, since the former has not been subjected to heat treatment which might cause protein denaturation and destruction of thermolabile amino acids such as lysine.

Waste loads in the various effluent streams may vary on a daily or even hourly basis. Analyses of variability in dissolved proteins in random collections of shrimp blanch water are shown in Figure 3. Waste load variability also is found in effluent blanch streams of the three canneries examined on the same day (Table 4). Dissimilarities exist not only in total dissolved and suspended wastes, but also in the relative amounts of the different components comprising the effluent loads. Variability may be due to such factors as size of shrimp, whether shrimp have been deveined, blanch period, temperature, and salinity. Nevertheless, plant-to-plant and day-to-day dissimilarities, depending on the tonnage being processed, ultimately can be calculated to provide an average amount of potential waste product recovery.

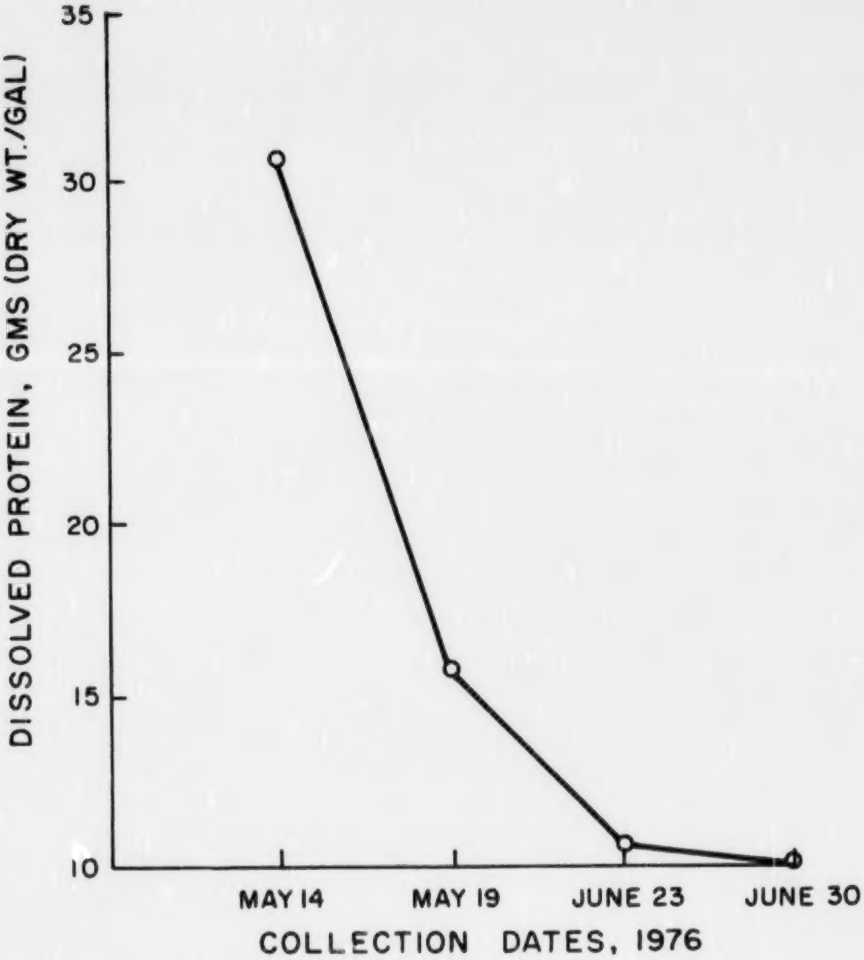

Figure 3. Variability of dissolved protein in shrimp blanch water (Plant A).

TABLE 4. VARIABILITY IN CONCENTRATION OF PROTEINACEOUS MATERIAL IN SHRIMP BLANCHING WATER*

Component	Plant A	Plant B	Plant C
Suspended meat fragments	40.8	0.8	7.4
Dissolved protein	12.5	25.2	25.0
Total	53.3	26.0	32.4

*Expressed as g (dry wt)/gal blanching water.

Another source of valuable shrimp meat is that from the discharge section of the forced-air apparatus used to remove debris (small meat pieces and shell fragments) originating from the turbulence of the blanching operation. In another plant, this material was separated by hand. In both facilities, the debris, including the food-grade shrimp meat pieces, are traditionally treated as waste and either are incorporated into the meal or are discarded entirely. Hand-separation of meat particles and shells revealed as much as 82% edible food-grade meat present. Based on a discard solid shrimp load weight of 500-1000 lb/8 hr, as much as 410-820 lb of valuable shrimp meat are discarded daily. Considering that often peak-load days run as long as 15-16 hr, along with the total number of processing days in a season and number of plants involved, clearly, multi-tons of valuable shrimp meat may be recovered.

Problems in load variability as noted earlier make any attempt to establish an average treatment of shrimp blanch water extremely difficult. Therefore, to effectively treat effluent streams, a monitoring system must be devised to indicate types and amounts of waste materials contained in such discharges. In a study of dungeness crab protein in Kodiak, Alaska in 1971(8) it was postulated that the protein solubility of dissolved crab protein in blanch water at the isoelectric point, in the main, was a linear function of the salt concentration. However, as noted in Figure 4, such a linear function is not totally applicable to shrimp blanch water. Although there appears to be a direct relationship between protein solubility and increasing salt concentration from specific gravity 1.025 to specific gravity 1.030, with increase in the specific gravity of the salt concentration to 1.040, the linear response becomes negative. This is also true when the salinity is decreased from specific gravity 1.040 to 1.030, accompanied by an increase in protein concentration. Thus, monitoring of salt concentration in shrimp blanch water does not appear to be a valid criterion of protein solubility; however, more detailed monitoring is necessary to detail quantitative aspects of salinity and dissolved protein levels. The extreme variations that occur in salt concentration over relatively short periods of time is also noted in Figure 4. This is due primarily to inadequate methods of monitoring blanch water salt concentrations during processing, which can give rise to an inconsistent product of less than optimal quality.

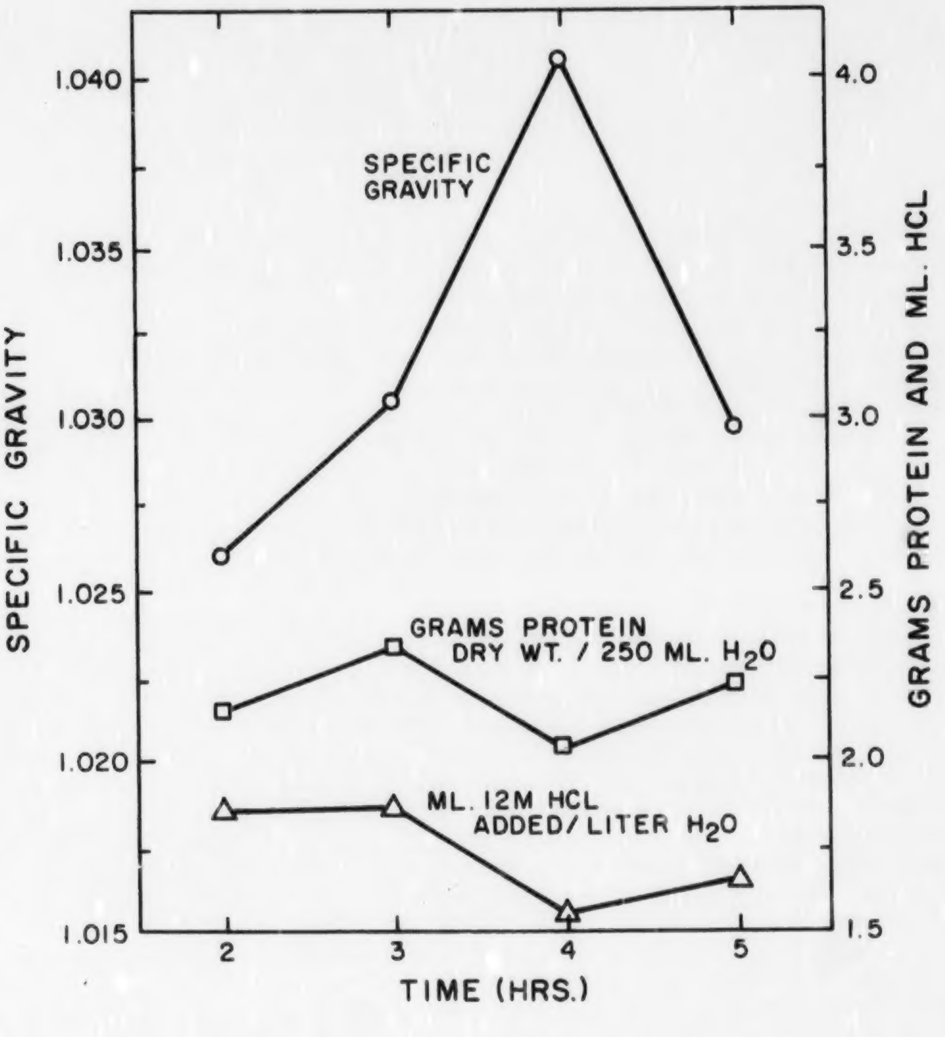

Figure 4. Blanch water concentration and recoverable protein (Plant A).

Total Carbon Determination-- Shrimp Blanch Water

The effectiveness of nutrient removal from the blanch water, using procedures of screening of meat fragments followed by chemical removal of dissolved protein and sugar, is seen in Figure 5. Data on carbon reduction are only qualitative representations of total reduction since no differentiation has been made between total organic and inorganic carbon levels.

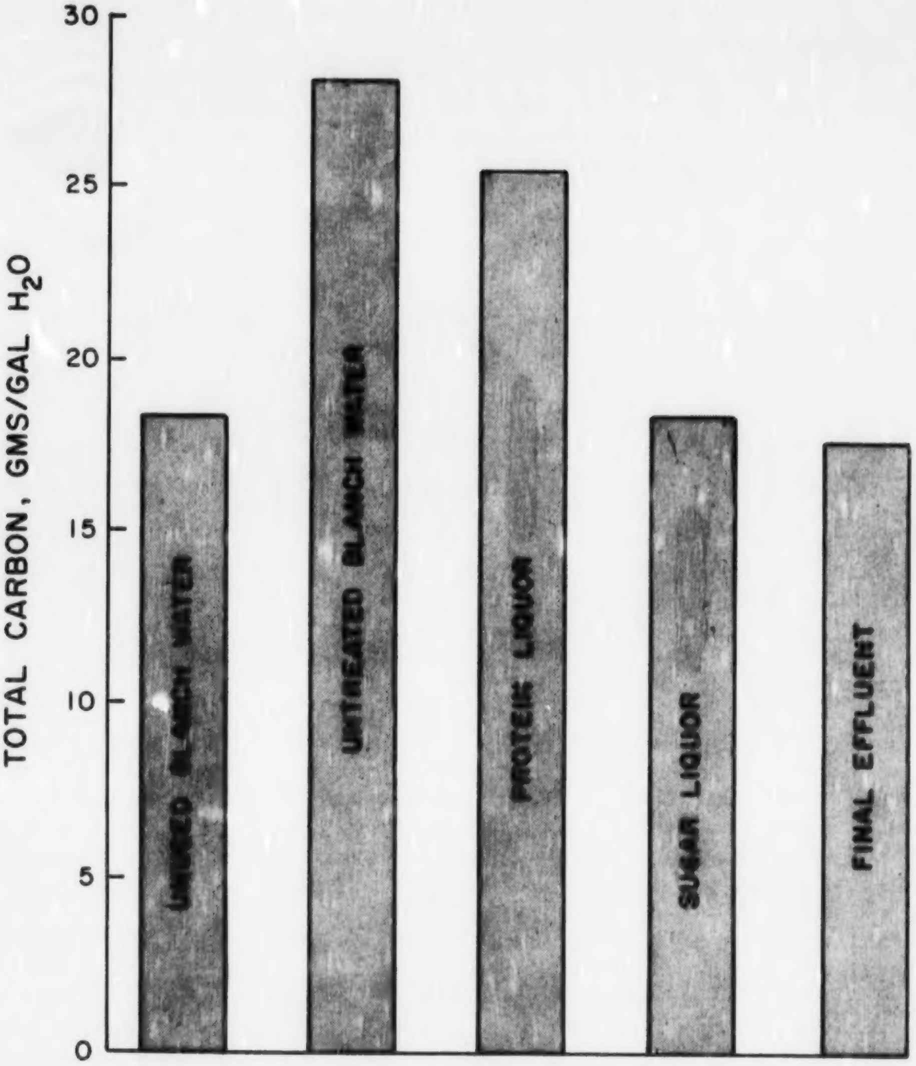

Figure 5. Reduction of total carbon in blanch water.

The maximal single reduction of total carbon occurred following removal of dissolved protein, i.e., an average of 7.3 g/gal. Since the shrimp contribute an average of 10.1 g C/gal of blanch water, dissolved protein removal alone accounts for a 73% removal of total carbon. The two other extraction procedures, i.e., removal of suspended meat fragments and dissolved "sugar," accounted for 26% and 4% reduction of total carbon, respectively. These values add up to a total of 103.0% of the 10.1 g C/gal contributed by the shrimp to the blanch water, suggesting that a portion of the carbon initially present in the fresh blanch water was also removed. Based upon the initial total carbon value of 18.1 g C contributed by each gallon of unused blanch water, and the final total carbon value of 17.8 g C in the final effluent, this method of treatment of the blanch water may be an effective means of reducing levels of biologically-active components present.

The overall potential shrimp protein recovery from a single plant, not including the multi-tons of solid waste incorporated into meal, is diagrammed below.

POTENTIAL SHRIMP PROTEIN RECOVERY
(Based on 8-hr day)

Peeling, Separating, and Deveining Streams	Blanch Stream	Raw/Cooked Debris and Shrimp Meat
↓	↓	↓
900-1100 lb/day	200-260 lb/day	500-1000 lb/day

Extrapolation of the above data to numerous localized plant operations over a concentrated processing season, with often 16-20 hours processing/day, indicates the significant magnitude of resource available for application.

Applications of Shrimp By-Products

Various uses for materials recovered from the shrimp processing operation are listed in Table 5. A diversity of applications are seen, including use in aquaculture diets, pet foods, concentrated flavor sources, additives to textured vegetable proteins for fabrication of shrimp products, and as a pigment source in broiler diets. Proposed usages for chitin and its derivative chitosan suggest further markets for exoskeleton waste.

An increasing amount of data is accumulating on analytical properties of shrimp meal and its application in animal rations. Use of such meals in poultry diets has been well demonstrated, especially for purposes of imparting desirable pigmentation to meat, skin or egg yolk. Frequently, source and type of the meal is not documented, a factor of considerable importance in view of the significant variability in proximate analysis of different processed shrimp meals(4).

TABLE 5. APPLICATION OF SHRIMP BY-PRODUCTS

Livestock Feed Ingredient	Source of:
Tropical Fish/Bird Diets	- Shrimp Protein Concentrate
	- Flavor Concentrates
Aquaculture Diets	- Carotenoid Pigments
Pet Food Supplement	- Chitin/Chitosan
Use in Fabricated Shrimp Products	

Earlier work from our laboratory(7) on analyses of nucleotides and amino acids in shrimp blanch water from batch tanks has revealed significant amounts of such materials. Concentrations of flavor enhancers such as IMP in blanch liquors are of particular interest. These studies have relevance to other fisheries industries using blanching procedures or where discharge streams carry large organic loads. Furthermore, analyses and quality evaluations of shrimp meal and in-plant streams, and development of nutritionally-sound shrimp meal-fortified diets, are needed for production of least-cost diets for cultivation of economically valuable aquatic animals. Analyses of shrimp waste protein, designated SWP(9), have revealed proximate values of protein as high as 59%. Further evaluation of such material(10) has shown that SWP has significant nutritive value, improving protein quality by 74% when soybean protein in the diet was replaced by 50% of SWP. Use of SWP in canned or processed pet foods, or as an additive to textured vegetable proteins, has been projected.

There is an increasing need to develop and improve aquaculture diets, based on workable feed formulation practices and good animal husbandry. More and more emphasis is being placed in aquaculture on effective use of industrial by-products or "wastes" as dietary ingredients to replace traditional feed commodities. Diet formulation practices must relate to current economics of marine and agricultural feedstuffs, problems of the seafood industry, and the state of the art in processing techniques. These food/feed related considerations are important in achieving economic viability in the nutrition and diet development phases of aquaculture. It has been demonstrated in our work, as well as in that of others, that shrimp by-products have valuable application in fish and crustacean diets(11).

Shrimp-based flake diets developed at LSU(12) have been used in nutrition of various fishes, especially freshwater and marine tropicals, specialty diets to enhance pigmentation, breeding, etc., and supplementation and ultimate replacement of currently used live food in aquatic animal culture. The tropical fish market is by no means insignificant. In analyses of sales of aquarium-related products, foods of various types showed a 17.5% increase in 1973-74, from 57 to 67 million dollars. Shrimp meals and pigment-fortified marine substrates are receiving increasing attention as skin/flesh coloration agents in salmon and trout diets(13). Shrimp protein, obtained as a by-product of a chitin-recovery operation, has been effectively used as a pigment and protein source in diets for pond/pen raised salmonid fish.

Recent studies have evaluated water-soluble proteins from autolyzed shrimp wastes as microbiological growth media. Data showed that a peptone derived from such wastes compared favorably with commercially available peptones in supporting growth of several microorganisms.

Considerable interest is being shown in recovery of chitin and chitosan, a polyglucosamine substance from chitin, from shellfish processing wastes. Commercial use of materials from the shrimp exoskeleton is being proposed in paper-making, pharmaceutical, food-processing, agricultural, waste treatment and monitoring, and adhesive industries. For instance, chitosan has been found to be an effective coagulating agent for poultry processing wastes wherein treatment reduced suspended solids in the composite effluents by as much as 74-95%. Savings in water and waste treatment costs, plus the value of coagulated solids as feed ingredients, may commend use of chitosan for pretreatment of poultry wastes and recovery of coagulated by-products.

Application of shrimp meat fragments is readily apparent in development of flavor concentrates, reconstituted shrimp and for use with texture soy protein in fabricated shrimp products. Lyophilized cooked shrimp protein concentrate has a strong shrimp flavor and a pinkish-orange color, along with a salty taste from the brine used. Both aspects can be adjusted via rehydration and comminution with vegetable protein extenders. A product such as this could be used as a mock shrimp for human consumption, requiring only formation of the shrimp-TSP mixture into a shape resembling a fantail or butterfly shrimp. Recent studies have shown that the shelf life of minced fish can be extended by comminution with shrimp meat. Rehydrated shrimp protein concentrate conceivably could be used in this process. Interest is being shown by food flavor industries in the potential of concentrated shrimp flavors in seafood products. The shrimp industry as a whole is looking into processes and products that will "extend" shrimp using procedures that combine shrimp meat and flavor with vegetable proteins and fillers (soy or rice), forming new products that can be competitive with other staple proteins.

Certainly, any consideration of economic recovery of blanch discharge, as well as materials from other plant streams, must involve specific plant characteristics as well as plant-to-plant variation, and logistics of collections. However, the volume of valuable proteinaceous material involved and increasing applications in food and feed industries is well documented. Further study of the reduction of waste loads in shrimp processing is warranted, coupled with in-depth evaluation of economics involved in use of the various recovered shrimp by-products.

ACKNOWLEDGMENTS

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REFERENCES

1. Meyers, S. P., and Rutledge, J. E. Economic utilization of crustacean meals. Feedstuffs 43:16 (1971).

2. Meyers, S. P., and Rutledge, J. E. Shrimp meal--a new look at an old product. Feedstuffs 43:31-32 (1971).

3. Meyers, S. P., and Rutledge, J. E. Utilization of economically-valuable byproducts from the shrimp processing industry. Food--Drugs from the Sea Proceedings, 1972 (ed. L. R. Worthen), Marine Technology Society, 75-85 (1973).

4. Meyers, S. P., Sonu, S. C., and Rutledge, J. E. Variability in proximate analysis of different processed shrimp meals. Feedstuffs 45:34 (1973).

5. Mauldin, A. F., and Szabo, A. J. Gulf shrimp canning plant wastewater processing. Proc. Fifth Nat. Symposium on Food Processing Wastes. EPA-660/2-74-058, p. 199-217 (1974).

6. Mauldin, A. F., and Szabo, A. J. Shrimp Canning Waste Treatment Study. U.S. Environmental Protection Agency Rept. No. EPA-660/2-74-061. (June 1974) 1-130.

7. Meyers, S. P., and Sonu, S. C. Nucleotides and amino acids in shrimp blanching water. Feedstuffs 46:23 (1974).

8. Johnson, E. L., Peniston, Q. P., and Braun, F. W. Pollution Abatement and By-Product Recovery in Shellfish and Fisheries Processing. U.S. Environmental Protection Agency Rept. No. EPA 12130 F-JQ 06/71. (1971) 1-85.

9. Toma, R. B., and Meyers, S. P. Isolation and chemical evaluation of protein from shrimp cannery effluent. J. Agric. Food Chem. 23:632-635 (1975).

10. Toma, R. B., and James, W. H. Nutritional evaluation of protein from shrimp cannery effluent (shrimp waste protein). J. Agric. Food Chem. 23:1168-1171 (1975).

11. New, M. B. A review of dietary studies with shrimp and prawns. Aquaculture 9:101-144 (1976).

12. Meyers, S. P., and Brand, C. W. Experimental flake diets for fish and crustacea. Progressive Fish Culturist 37:67-72 (1975).

13. Meyers, S. P. Use of crustacean meals and carotenoid-fortified diets in aquaculture. Feedstuffs 49: (1977).

TOXICITY OF SOME CANADIAN FRUIT AND VEGETABLE PROCESSING EFFLUENTS

by

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INTRODUCTION

Fruit and vegetable processing operations are the source of a concentrated biologically-active effluent and highly putrescible solid wastes which must be treated and ultimately discharged to the land surface or a water body. Stringent control measures are likely to be required in many cases to avoid overloading the local assimilation capacity, while in other cases much less stringent controls would be appropriate. An objective of regulatory agencies is to establish rational effluent standards which will prevent pollution by fruit and vegetable processing wastes, yet which will represent practical, attainable goals. The costs of alternative abatement strategies must be carefully evaluated as these will either be passed directly to the consumer or, if this is prevented by competitive forces, may threaten the continued economic operation of the facility.

In recent years there has been a growing awareness of environmental issues by Canadians. The Federal Government responded to this public concern by putting forward a major legislative program, the focal point of which was the Government Organization Act resulting in the formation of a Department of Environment in June 1971. The Environmental Protection Service (EPS) was developed to cover the specific responsibility for environmental protection. The role of EPS is one of problem identification and solution, being concerned with the control and abatement of pollution by formulating a realistic program of pollution control for Canada in cooperation with provincial authorities and industries concerned.

The approach of the Environmental Protection Service to pollution control is to adopt a strategy of containment at source by means of the best practicable technology. The regulations and guidelines developed to achieve this strategy are based on control methods which are the best from both an economic and environmental standpoint. Every effort is made to ensure the fullest participation of provinces and industries concerned, the first steps being to identify the problem in terms of an environmental inventory of the industry and to conduct a "state-of-the-art" review including waste characterizations, and process and waste treatment technologies. A Federal/Provincial/Industrial task force assesses this information and recommends best practicable in-process and treatment technology on which to base effluent regulations or guidelines. These regulations or guidelines, as formulated by the Environmental Protection Serivce, are subsequently reviewed with the provincial pollution control agencies, the appropriate Canadian industry associations and international experts in the field with the objective of obtaining a general concensus on the soundness of the regulations or guidelines.

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The work described in this paper is the result of two projects carried out by Stanley Associates Engineering Ltd. for the Canadian Federal Government; a state-of-the-art review of waste treatment technology in the fruit and vegetable industry, and an inventory of plants in Canada.

This work is now completed and will be published shortly by the Federal Government.

DATA SOURCES

Prime sources of data for plants in the Canadian fruit and vegetable processing industry were those individual plants at which site visits were carried out during the course of the state-of-the-art review and the responses to questionnaires distributed by Environment Canada to all known Canadian fruit and vegetable processors during the Inventory Study.

Data have been presented in this paper in the metric system of units. A table showing various conversion factors applicable to the fruit and vegetable industry is given in Appendix 1.

FRUIT AND VEGETABLE PROCESSING INDUSTRY

Canadian Operations

It is recognized that the fruit and vegetable industry is complex; thus eleven major commodities were designated in the original work.

- Apples and apple sauce
- Peaches, pears and apricots
- Cherries and plums
- Berries
- Corn
- Peas and beans (Blanched vegetables)
- Beets and carrots
- Tomatoes
- Sauerkraut
- Pickles and relishes
- Jams and Jellies

It is considered that the above list of commodities reflects the major fruits and vegetables processed in Canada based on a review of Canadian statistics. It should be pointed out that this list is not exhaustive with respect to the total processing industry in Canada nor does it include all the specific commodities discussed in recent publications by the United States Environmental Protection Agency.

The Canadian fruit and vegetable processing industry is a multi-million dollar manufacturing activity. The value of shipments of manufactured goods in 1974 totalled approximately 865 million dollars. Three provinces, British Columbia, Ontario and Quebec are the major processing areas contributing 9%, 62%, and 15% of the total value of shipments, respectively.

Based on information available from Statistics Canada and other sources, the weights of raw fruits and vegetables processed in Canada in 1975 were estimated to be as follows:

Raw fruit processed	249,870 metric tonnes
Raw vegetables processed	851,580 metric tonnes

The total number of plants in Canada processing raw fruits and vegetables is estimated to be 221. Large plants, that is those processing greater than 10,000 metric tonnes of raw material annually constitute only 10% of the total number of plants, yet account for 51% of the total Canadian production. In contrast, small plants, or those processing less than 2,000 metric tonnes of raw material annually constitute 50% of the total number of plants but account for only 7% of the total production. The remaining 40% of the plants process between 2,000 and 10,000 metric tonnes annually and account for 42% of the commodities produced.

Wastewater Loadings

Using data for the year 1975 obtained from questionnaires developed by Environment Canada and distributed to all known Canadian fruit and vegetable processing plants, estimates of total potential raw wastewater BOD_5 and suspended solids loadings from the industry were as follows:

	BOD_5 (kg)	S.S. (kg)
Small Plants	0.82×10^6	0.30×10^6
Medium Plants	5.73×10^6	1.87×10^6
Large Plants	5.47×10^6	2.99×10^6
Total	12.02×10^6	5.16×10^6

Existing (1975) treatment systems are removing 76.2% of the total BOD_5 and 79.8% of the total suspended solids loadings broken down as follows:

	BOD_5	S.S.
% Removed by Industry operated biological treatment systems	30.7	30.8
% Removed by municipal systems	29.8	31.0
% Removed by land application systems	15.7	18.0
Total Removed (%)	76.2	79.8

EFFLUENT REGULATIONS

Effluent regulations are being established for many Canadian industries by Environment Canada. These regulations generally specify a permissible quantity of pollutant which can be discharged per ton of material processed or per ton of finished product (eg. lbs. of BOD_5 or suspended solids per ton of product). Effluent toxicity is another parameter frequently specified in effluent regulations. The toxicity clause specifies a concentration of diluted effluent in which rainbow trout must survive for 96 hours in a flow through bioassay test.

The reasons for specifying a toxicity limit are twofold. First, fish have direct value to the public both as a food source and for recreational purposes. The Canadian Government is interested in protecting this resource. Secondly, from the point of view of the regulatory agency, a toxicity standard simplifies the effluent monitoring program. It would be difficult if not impossible to perform routine testing for all toxic compounds which may be present in a waste. Specifying a toxicity standard enables the agency to control pollutant levels for many toxic parameters by performing the bioassay test.

WASTEWATER TOXICITY

Wastewater may contain many materials which can cause mortality or adversely upset biochemical functions of aquatic organisms. The bioassay test measures acute lethal toxicity; that is, the ability of a waste to cause death of the test organisms usually within a period of four days. Such effects as a pH change which inhibits the transfer of soluble materials and gases or the presence of high concentrations of suspended solids which result in physical abrasion or clogging of the gills are frequently responsible for acute toxicity.

It should be noted that the bioassay test gives no indication of sub-lethal effects such as destruction of habitat or food chain organisms or interference with behavior or reproduction patterns. These could be as lethal as acute effects in the long term.

A direct physical or chemical analytical procedure can be used to measure the level of those physical and inorganic sources of toxicity. Receiving water and effluent standards can then be set to protect fish and other aquatic species. However, where complex organic compounds cause acute or sublethal toxicity, direct analytical techniques have not been developed for water quality control purposes.

In many wastewaters the specified compound causing toxicity is not definitely known. Bioassay testing is therefore utilized to detect the presence and concentration of toxic compounds in wastewater effluents. Any aquatic species which are sensitive to pollutants could be utilized as a test organism but fish have been chosen as the test animals for most toxicity work.

In Canada, the Fisheries Act is the legislation under which water pollution control regulations are promulgated and therefore the use of fish species for bioassay testing is appropriate. Although fish may not be the most pollution sensitive species in the adult form, they have the most direct value to the public as a food source or sporting activity.

Bioassay Test Method

The bioassay test involves observations of fish mortality in varying concentrations of effluent. Rainbow trout are used as the test species because: (1) there is an abundance of data on their response, (2) they are a common and popular game fish, and (3) they are a particularly pollutant intolerant species.

Large volumes of wastewater are collected over a 24 hour period, refrigerated to 5°C and shipped to the test facility. Varying concentrations of waste and dilution water are prepared in the range of 0 - 100%. The 0% or control sample, consisting entirely of dilution water, must have less than 10% deaths or the test is considered invalid.

The test conditions are defined and are carefully controlled. Temperature is usually maintained at 15°C ± 1°C. Aeration is supplied to provide a minimum dissolved oxygen concentration of 8 mg/l. pH may or may not be adjusted depending upon the objectives of the test. Fish size and volume of test solution are also controlled. Fish which have been acclimated to dilution water are then introduced into each of the vessels containing a different concentration of waste.

Ideally, a continuous flow (once through) system is used to prevent accumulation of waste materials generated by the fish or depletion of toxic materials in the effluent sample. However, continuous flow bioassays require elaborate equipment and relatively large waste samples (up to 1000 gallons as compared to 50 to 100 gallons for static testing). Continuous flow testing therefore tends to be much more expensive and difficult to run than the simpler static test. As a result there is usually an attempt to develop a correlation between flow through and static tests so that the latter can be used for routine monitoring purposes.

Fish deaths are observed and recorded at regular intervals for a 96 hour period. The percent mortality at 96 hours in each test vessel is then plotted against the effluent concentration in the vessel on semi-logarithmic probability paper and the best straight line fitted through the data as shown in Figure 1. The parameter used to describe effluent toxicity is the LC_{50} value or the lethal concentration for 50% mortality. It is the effluent concentration at which 50% of the test organisms would die in 96 hours. It should be noted therefore that the smaller the LC_{50} value the more toxic the waste.

The toxicity levels utilized in reporting results were as follows:

Non Toxic - no mortality during the 96 hour test at any effluent concentration including undiluted effluent.

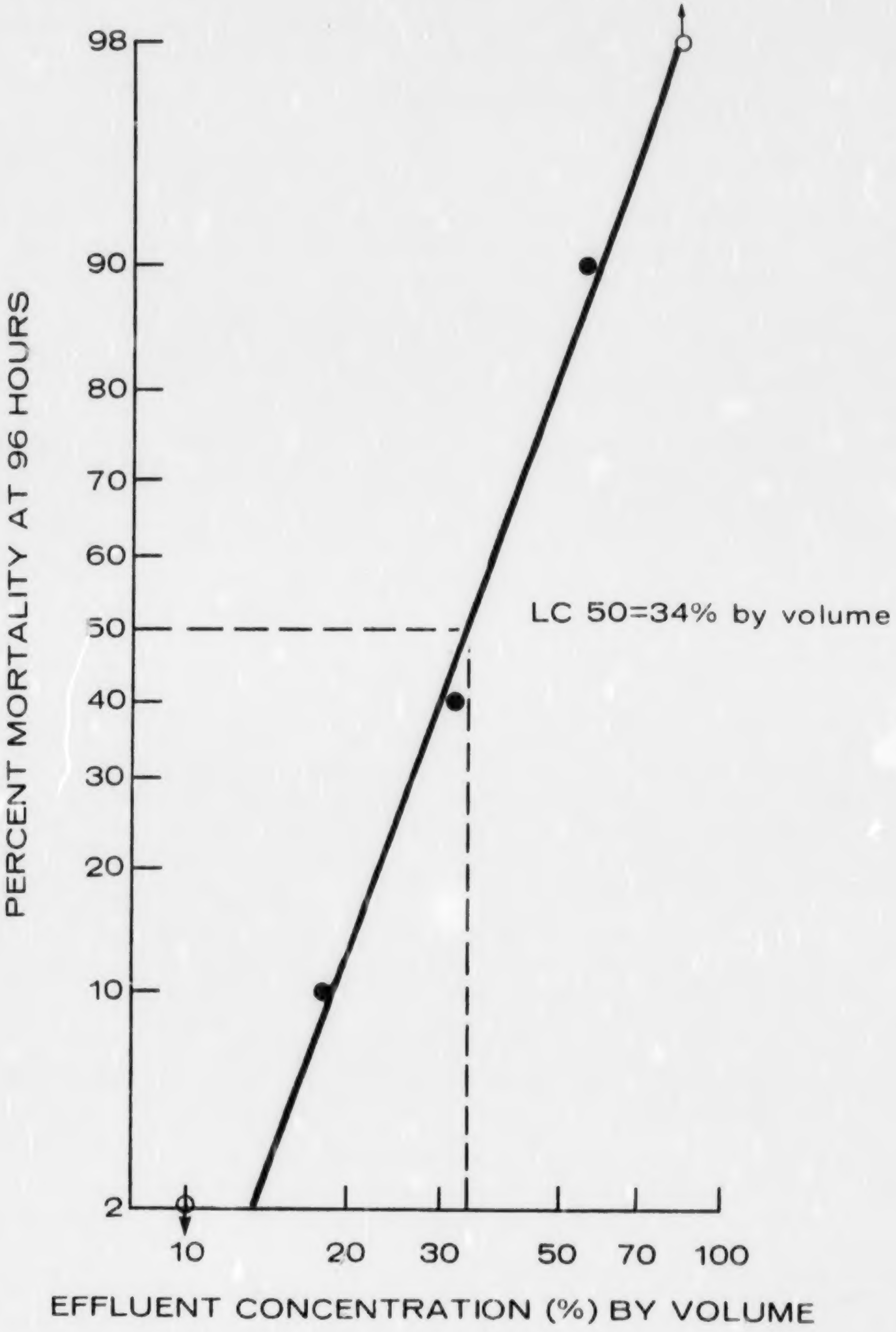

FIGURE 1. Plot of Bioassay Test Results (After Bissett; 1975).

Partly Toxic - a number of fish die in the test but less than 50% of them.

LC_{50} - 1 - 100% - half of the fish die in a 96 hour period in the concentration of effluent specified.

FRUIT AND VEGETABLE PROCESSING WASTEWATERS

Raw Screened Wastewater Quality

The data presented in Table 1 was compiled as a result of site visits to eight Canadian fruit and vegetable processing plants. Raw waste samples could only be obtained at the five plants shown. Raw screened wastewater from all plant samples was high in biologically degradable material as evidenced by BOD_5 values generally ranging between 500 and 2000 milligrams/litre. Suspended solids concentrations typically fell between 300 and 500 milligrams/litre.

LC_{50} values were also obtained for the wastes using 96 hour static bioassay testing. All wastes exhibited acute toxicity to rainbow trout with LC_{50} values ranging between 12 and 36%. From inspection of these results, it would appear that the toxicity is probably due to the high concentrations of suspended solids and organic material. The number of samples obtained during the study were not sufficient to state the cause of the toxicity with any statistical reliability.

An examination of the raw waste toxicity in terms of LC_{50} was also made at 24, 48, and 72 hours as shown in Table 2. It is apparent that the 72 hour value is in virtually all cases identical to the 96 hour static bioassay test results. Similarly, in most cases the 48 hour LC_{50} value is also in very close agreement with the 96 hour value. However, as there is a significant difference between the 24 hour and 48 hour values, it would be advisable to utilize a minimum duration of 48 hours in future testing.

Treated Effluent Quality

Treated effluent quality for the eight plants surveyed is illustrated in Table 3. These plants demonstrated performance somewhat better than the Canadian average with BOD_5 and suspended solids removals generally greater than 80%.

Toxicity was eliminated in effluent from all plants with the exception of two of three corn processors.

At plant number 3 where effluent LC_{50} values of 50%, 71%, 75% and 100% were recorded, treatment consisted of an aerated lagoon with settling. Raw screened effluent samples were not available from this plant and consequently raw waste toxicities could not be determined. However, treatment of corn processing wastewaters exhibiting raw wastewater toxicity of 18.0 and 17.0% at plant numbers 5 and 8, respectively, was successful in reducing the effluent toxicity to the point where less than 50% of the test fish died in full strength effluent.

TABLE 1

RAW SCREENED WASTEWATER CHARACTERISTICS

Plant No.	Commodity	BOD_5	SS	pH	Total P	TKN	LC_{50}
4	Tomatoes	100-610	183-364	4.7-10.2	4.4-9.7	2.5-18.2	13.5-36.0%
5	Corn	494-1400	162-488	4.6-5.3	3.0-12.0	5.2-14.9	18%
	Beets	1650-4940	402-675	5.0	4.3-12.0	10.0-16.6	12.5%
6	Apples	748-2880	56 - 178	7.3 - 7.4	9.8 - 11.2	0.9-16.8	N.T.-P.T.
7	Apples, Oranges & Pears (Juice Plant)	875-5300	26-2510	5.6-8.2	0.5-3.8	0.8-18.5	----
8	Corn, Plums Jam, Broccoli	1182-5108	320-580	5.3-7.2	1.0-4.6	0.5-2.5	13%-17%

NOTE: N.T. - Non-toxic
P.T. - Partly toxic

TABLE 2

COMPARISON OF LC_{50} FOR VARIOUS STATIC TEST DURATIONS - RAW SCREENED WASTEWATER

Commodity	24 Hr	48 Hr	72 Hr	96 Hr
Apples	- 38.0	24.0 38.0	24.0 38.0	24.0 27.0
Beets	21.0	12.8	12.5	12.5
Corn	23.0	20.0	18.0	18.0
Corn	16.0 18.0	13.0 17.0	12.5 17.0	12.5 17.0
Tomatoes	45.0	36.0	36.0	36.0
Tomatoes	42.0	42.0	13.5	13.5

TABLE 3

TREATED EFFLUENT CHARACTERISTICS

Plant No.	Commodity	Waste Treatment Process	BOD_5	SS	pH	Total P	TKN	LC_{50}
1	Tomatoes	Spray Irrigation	81-90	28-48	7.3-7.4	0.5-0.7	1.1-1.4	N.T.
2	Pears	Spray Irrigation & Holding Pond	924-1532	86-89	6.6-7.1	2.1-2.9	2.2-3.2	N.T.
3	Corn	Aerated Lagoon & Sedimentation	415-435	1730-3250	7.0-7.7	9.5-26.0	40.4-76.2	100% 71% 75% P.T.
4	Tomatoes	Trickling Filter Aerated Lagoon & Settling	5-19	6-19	6.2-7.4	0.4-4.0	0.4-2.3	N.T.
5	Corn Beets	Spray Irrigation	366-374 148-234	26-55 21-22	7.0-7.6 6.3-7.1	0.5-1.1 0.2-0.25	1.4-1.6 1.0-1.6	P.T. N.T.
6	Apples	Aerated Lagoon	158-1400	31-42	7.3-7.4	9.8-11.2	0.9-16.8	N.T.
7	Apples, Oranges & Pears (Juice Plant)	Aerated Lagoon & Sedimentation	15-95	15-63	7.7-8.1	0.5-1.3	1.0-2.0	N.T.
8	Corn, Plums, Jam & Broccoli	Oxidation Ditch & Settling	1145-1685	240-370	6.1-7.3	0.1-4.3	1.0-2.6	N.T.

NOTE: N.T. - Non-toxic
P.T. - Partly toxic

Examination of the chemical analyses of the toxic effluents shows that there is no firm relationship between toxicity and measured parameters, with the exception of suspended solids concentration. In the case of the treated corn processing wastes which exhibited LC_{50} values ranging from greater than 50% to 100%, there were high total Kjelkahl nitrogen concentrations indicative of high protein content. It should be noted that wastewater effluents from the meat processing industry exhibiting high protein levels have been shown to exhibit high toxicity.

Conclusions

A number of conclusions can be reached regarding the toxicity of effluents from the fruit and vegetable processing industry based on the limited amount of data obtained from the plant surveys.

1. Raw screened wastewaters from the following commodities demonstrate toxicity to rainbow trout, based on static 96 hour bioassays:

   Tomatoes
   Corn
   Beets
   Apples
   Corn, plums, jam
   Corn, plums, broccoli, jam.

2. No definite chemical cause for toxicity could be determined from the limited testing program.

3. Corn processing wastes were the most toxic of the wastewater effluents examined. Since corn makes up a considerable percentage of Canadian vegetable processing, further investigation is required to determine the causes and methods to reduce the toxicity of corn processing effluents.

4. The high organic nitrogen content of the corn processing effluents may have been contributory to effluent toxicity.

5. It was found that 48 hour LC_{50} values on raw screened wastewater were in very close agreement with 96 hour static bioassay test results. However, it is recommended that a minimum duration of 48 hours be used in future testing, as there was a significant difference between 24 and 48 hour LC_{50} values.

6. The toxicity level which could be specified in the regulations for fruit and vegetable processing wastewater effluents is no acute toxicity in full strength effluent.

Only a limited number of raw and treated effluents from selected fruit and vegetable commodities were tested. For each industrial effluent sampling was also limited. Since acute toxicity was found to be a problem with corn wastes, processing wastewaters from all commodities should be tested for toxicity before and after biological treatment on a statistical reliable number of samples. As well, where toxicity persists after secondary treatment, specific cause of toxicity should be determined.

TABLE A1.

CONVERSION FACTORS

English Unit	X	Multiplier	=	S.I. Unit
acre		4,046		m^2
acre		0.405		ha
acre-ft		1,234		m^3
cu ft		0.028		m^3
cu in		16.39		cm^3
cfm		0.2832		m^3/min
cfs		1.70		m^3/min
ft		0.3048		m
°F		0.5555 (°F-32)		°C
gal (Imp)		0.004546		m^3
gal (US)		0.003785		m^3
gpd/sq ft (US)		0.0408		m^3/day/m^2
gpm (Imp)		0.2728		m^3/hr
gpm (US)		0.2271		m^3/hr
in		2.54		cm
lb (mass)		0.4546		kg
lb/cu ft		16.02		kg/m^3
lb/1000 cu ft		16.02		g/m^3
lb/day/acre		0.112		g/day/m^2
lb/day/acre - ft		3.68		g/day/m^3
lb/day/cu ft		16.02		kg/day/m^3
lb/day/sq ft		4.880		g/day/m^2
lb/day/1000 sq ft		4880		g/day/m^2
lb/ton		0.5		kg/t
mgd (Imp)		4546		m^3/day
mgd (US)		3,785		m^3/day
sq ft		0.09290		m^2
ton		9072		kg
ton		0.9072		t

TABLE A2

SYMBOL DEFINITION

Symbol	Definition
cu ft	cubic feet
in	inch
cfm	cubic feet per minute
cfs	cubic feet per second
gpd	gallons per day
lb	pound
sq ft	square foot
ton	short ton
mgd	million gallons per day
m	metre
ha	hectare
cm	centimetre
kg	kilogramme
t	metric tonne

REDUCTION OF WASTES FROM CUCUMBER PICKLE PROCESSING BY USE OF THE CONTROLLED CULTURE FERMENTATION PROCESS

by

L. W. Little*, R. Harrison**, J. Davis*, J. Harris**, and S. J. Dunn**

INTRODUCTION

Several years ago Hoover (1) posed the question which must be answered in regard to prevention of food processing wastes: "Can we change existing processes so that less waste is produced, while maintaining or improving product quality?" The objectives of the project described herein were addressed to answering this question in regard to the cucumber pickle industry:

(1) to demonstrate on a commercial scale a substantial reduction in salt usage in brining cucumbers by substitution of the controlled culture fermentation (CCF) procedure for the currently used natural fermentation (NF) procedure
(2) to compare progress of controlled culture fermentations and natural fermentations under actual tankyard conditions
(3) to compare quality of brinestock and pickles produced by CCF with those produced by NF

Currently about 50-60 per cent of the cucumber pickles which are produced in this country are prepared from brinestock. In this case, the cucumbers are brought in from the fields, placed in a salt brine of approximately 25° salometer strength and allowed to ferment naturally. The bacteria and other microorganisms indigenous to the cucumbers and attached soil ferment sugars which leach out of the cucumbers, converting them to acid endproducts. The main function of the brine is to inhibit growth of undesirable microorganisms while favoring growth of lactic acid producers such as *Lactobacillus* species. After the active fermentation period, when the sugars have been consumed, the pH has dropped to about 3.5, and sufficient acidity has developed, the brined cucumbers may be stored for 3 months or more before they are used to

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prepare finished pickles. During the storage period the salt concentration is gradually increased to 45-60° salometer in order to stop bacterial activity and preserve the cucumbers.

When the cucumbers are removed for processing, the spent brine is drained off and is usually discharged directly (via a pipeline) or indirectly (via drainage onto the tankyard and subsequent runoff) into the plant's wastewater treatment system. The discarded brine has a high pollution potential (Table 1) and accounts for most of the salt in the wastewaters from pickle manufacturing (2). Since salt is unaffected by activated sludge or aerated lagoons, the usual methods of wastewater treatment, it passes into the effluent and thence to a receiving stream or to a municipal wastewater treatment plant. If inadequate dilution with freshwater is not available, the salt can cause high total dissolved solids levels which render the receiving stream unfit for aquatic life, for irrigation, or for a potable water source. It is anticipated that effluent guidelines will soon require greatly reduced dissolved solids levels in effluents from pickle plants which discharge to freshwater streams or to municipal wastewater treatment plants.

TABLE 1. TANKYARD BRINE COMPARED TO TYPICAL DOMESTIC SEWAGE

Parameter	Brine	Sewage
TOC, mg/l	3400	124
SS, mg/l	330	170
Kjeld-N, mg/l	732	31
TP, mg/l	87	10
Cl, g/l	111	<1
pH	3.4	7.2

In addition, the high salt levels can interfere with operation of the plant's biological treatment system, and they represent loss of salt, an ingredient which is cheap on a cost per unit weight basis but which is expensive in terms of the total amount required for pickling or in terms of cost to remove it from the wastewater. These and other pollution problems associated with tankyard operations have been analyzed extensively in a previous report (2).

Despite the heavy use of salt, natural fermentations have been described as "unrestricted, heterogeneous, highly complex, and variable," often leading to production of defective brinestock (3). Lowered brinestock quality is especially apt to occur if pectinase-producing yeasts or coliform-type bacteria grow in the brine, Because of the problems and the unpredictability of natural fermentations, the U. S. Food Fermentation Laboratory has developed the controlled culture fermentation (CCF) process (3). CCF brining procedure includes washing the cucumbers before they are tanked, sanitizing the cucumbers and the tanks with brine containing a small amount of chlorine, and inoculating the brine with concentrated cultures of rapid-growing lactic acid bacteria. Because most of the undesirable microorganisms have been eliminated by the washing and sanitizing procedures, and because the heavy inoculum of the **lactic acid** bacteria tends to suppress growth of any which have survived these procedures, the fermentation takes place rapidly and high levels of acidity are quickly achieved. If freezing weather conditions are not a consideration, the brinestock can be stored at 25° salometer (6.6%), requiring about half or less of the salt commonly used.

The CCF process had been extensively tested in the laboratory and in relatively small tankyard studies (3). However, studies on a larger scale, accompanied by assessment of the potential for reducing pollution, had not been conducted.

This project was initiated in 1976. Funded jointly by the U.S. Environmental Protection Agency and the Perfect Packed Products Division of the Heinz Co., Henderson, N. C., the project was conducted by scientists from North Carolina A & T State University and the University of North Carolina at Chapel Hill with aid of Heinz personnel and the U.S. Food Fermentation Laboratory.

Three tankyard experiments were conducted during the 1976 green season. In each case, CCF and NF tanks were set up and fermentation progress, brinestock quality and quantity, spent brine quality and quantity, and finished product quality and quantity were compared.

MATERIALS AND METHODS

Materials

Tanks. The Heinz Company provided 800-gallon wooden vats coated with fiberglass and fitted with stainless steel sampling channels. Vats used for CCF were **fitted** with a nitrogen purging system comprised of a loop of tubing pierced with holes (1/64-in) connected to a tank of compressed nitrogen. A rotometer and flow-control valve were used to measure and control N_2 flow. CCF tanks were purged continuously during the initial phases of the fermentation at a rate sufficient to keep CO_2 concentrations below 20 mg/100 ml. NF tanks were not purged. Before the tanks were covered with plastic netting the tanks were headed by widely spaced wooden boards in which holes had been drilled to facilitate gas exchange.

Cucumbers. Size 3 (1 1/2-2" in diam) cucumbers were used for all experiments as it was felt that the large size would be the most likely to bloat and would thus provide the most stringent test of the CCF procedure. The green stock was obtained from that being supplied to the pickle company. The percentage of solids to liquids was 65% cucumbers and 35% brine (wt/wt).

Salt. The salt used was the rock salt commonly used at the plant.

CCF procedure. The CCF procedure was that suggested by Etchells et al (3). In-tank shrinking was employed. Chlorination was achieved by addition of calcium hypochlorite (Lo-Bax^R, Olin Corporation). The only exception to the procedure was omission of the second chlorination 10-12 hours before inoculation. It was assumed that sufficient sanitizing was provided by the washing and initial chlorination and that further chlorination after the cucumbers had been soaking in the brine might cause production of undesirable chlorinated organic compounds.

Cultures. Cultures of *Lactobacillus plantarum* were obtained from Chr. Hanson Laboratories and Miles Laboratories.

NF procedure. The NF procedure was that commonly used by the pickle company.

Routine analyses. Salt concentration was measured with a salometer. Acidity was measured as lactic acid by titration with 0.1 N sodium hydroxide, using phenolphthalein indicator. Temperature was measured with an ordinary laboratory thermometer. CO_2 was estimated by a modification of the Harleco procedure (4) .

Brinestock evaluation. Representative samples of brinestock were obtained by passing a lucite cylinder (1 ft ID) to the bottom of the tank and removing all the brinestock by netting. Two cores were removed from each tank. The brined cucumbers were cut longitudinally and examined for balloon, honeycomb, and lens type bloaters (5). Texture was evaluated with a Maagdeborg pressure tester.

Finished product evaluation. The brinestock was used to prepare hamburger chips and whole dill pickles, packed in 5-gal plastic pails. Chips and whole pickles were taken from selected pails, coded, and evaluated by a panel of 6 to 8 persons, using the rating sheet devised by the U. S. Food Fermentation Laboratory.

RESULTS AND DISCUSSION

During the project three experiments were conducted. During experiment I two tanks were brined, one NF and one CCF; during experiment II, two NF and two CCF; and during experiment III, one NF and two CCF. Figure 1 shows the progress of fermentation in the tanks, as indicated by lactic acid product. In the case of duplicate tanks, the average value is shown. The median afternoon brine temperatures were 80.5 °F (Experiment I); 84.2 °F (Experiment II); and 84.8 (Experiment III).

The initial acidity was higher in CCF tanks due to the initial addition of acetic acid, as directed in the CCF procedure. Note that the rate of acid production was generally more rapid in CCF tanks and that higher final acidities were attained in these tanks. This indicates **the rapid and** desirable activity of the bacteria used for the inoculum, and it also indi-

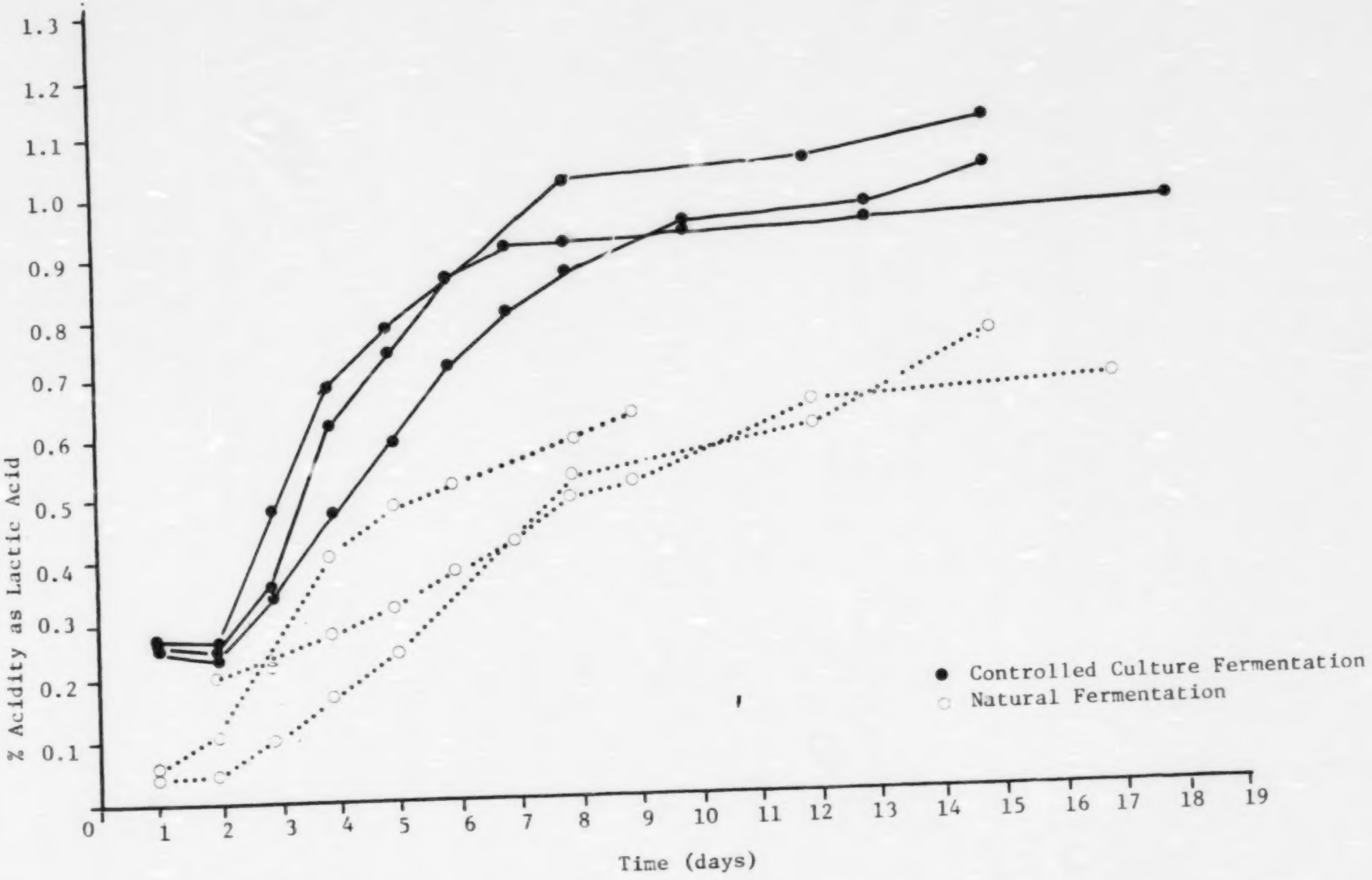


Figure 1. Comparison of lactic acid production in controlled culture and natural fermentations (three experiments).

cates that the fermentation time can be shortened by use of the CCF procedure.

In each case the brinestock produced in the vats was evaluated for texture and for defects, especially evidence of bloating. The overall acceptability and determination of usable brinestock was computed by numerical systems developed by Fleming et al (6) and by S. D. Rubin of the Heinz Co. A summary of the evaluation is shown in Table 2, which indicates that CCF brinestock had slightly better texture than NF brinestock and that CCF brinestock typically had a low bloater index. It is also apparent that the quality of CCF brinestock was much more consistent and predictable than that of NF brinestock, despite the fact that the NF experimental tanks received much more attention than would a tank in the average tankyard. It can be concluded that there would be considerably less waste of brinestock from CCF tanks.

TABLE 2. EVALUATION OF BRINESTOCK FROM NATURAL FERMENTATIONS AND FROM CONTROLLED CULTURE FERMENTATIONS

	Pressure Test		Examination for Freedom from Defects		
Expt.	#Tested	Average (lb)	# Examined	Estimated Yield (%)[1]	Bloater Index[2]
Natural Fermentations					
I	40	16.7	200	82.4	13.8
II	40	20.0	200	97.0	1.1
	40	17.0	200	96.0	1.6
III	40	20.5	160	78.0	17.2
Average		18.6		88.4	8.4
Controlled Culture Fermentations					
I	40	17.8	200	97.5	2.1
II	40	19.5	200	93.0	1.9
	40	18.5	190	92.5	1.2
III	40	21.5	200	97.5	1.0
	40	22.0	200	95.5	2.3
Average		19.9		95.2	1.7

[1] Using system devised by S. D. Rubin, Perfect Packed Products, Inc.
[2] Fleming et al (6)

The finished products from 6 of the experimental tanks have been evaluated by a six-member panel made up of USDA, Perfect Packed Products, and A & T personnel. Hamburger chips and whole dills were prepared. Figure **2 indicates** that in terms of appearance, taste, and texture, the chips **are** very similar in quality and compare well with those produced commercially. Figure 3 **indicates** that appearance and texture of whole dills prepared from CCF is notably better than those from NF, while taste ratings **are** similar.

Table 3 shows the volume and salt loading of the wastewaters from the two processes. Unexpectedly, the volume of wastewater generated by the two processes did not differ greatly. Part of this can be explained by the failure to sufficiently desalt the NF brinestock in the first experiment. In addition, it was observed that the plant personnel tended to vary time of desalting based on the amount of salt left in the cucumbers. On the other hand, in terms of salt to be discharged in the wastewaters there is a very striking difference in the two types of fermentations. This difference would be greater if the tanks were held for longer periods and salt addition to NF tanks continued.

In summary, the following conclusions may be drawn:

1) CCF fermentations proceed more rapidly and result in higher levels of acidity than do natural fermentations
2) CCF produces superior brinestock quality
3) CCF results in dramatic reduction in amount of salt to be discharged
4) Whole dills produced from CCF are equal in taste and superior in appearance and texture to those from NF
5) Hamburger chips from the two processes are similar.

This study was conducted as part of a contract under the sponsorship of the U. S. Environmental Protection Agency in cooperation with Perfect Packed Products Co., Inc., Division of H. J. Heinz Co.

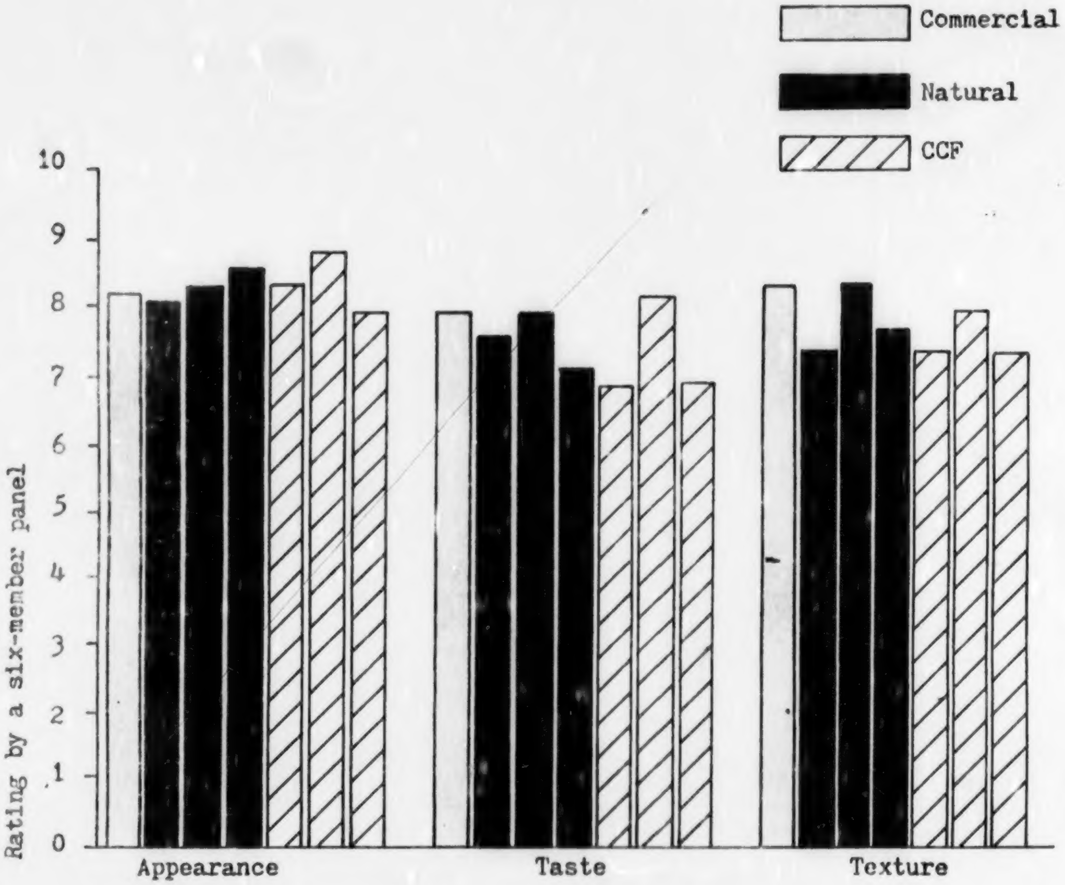
REFERENCES

1. Hoover, S. R. Prevention of food-processing wastes. *Science 183*: 824 (1974).

2. Little, L. W., Lamb, J. C., and Horney, L. F. Characterization and Treatment of Brine Wastewaters from the Cucumber Pickle Industry. UNC Water Resources Research Institute Report No. 99 (1976).

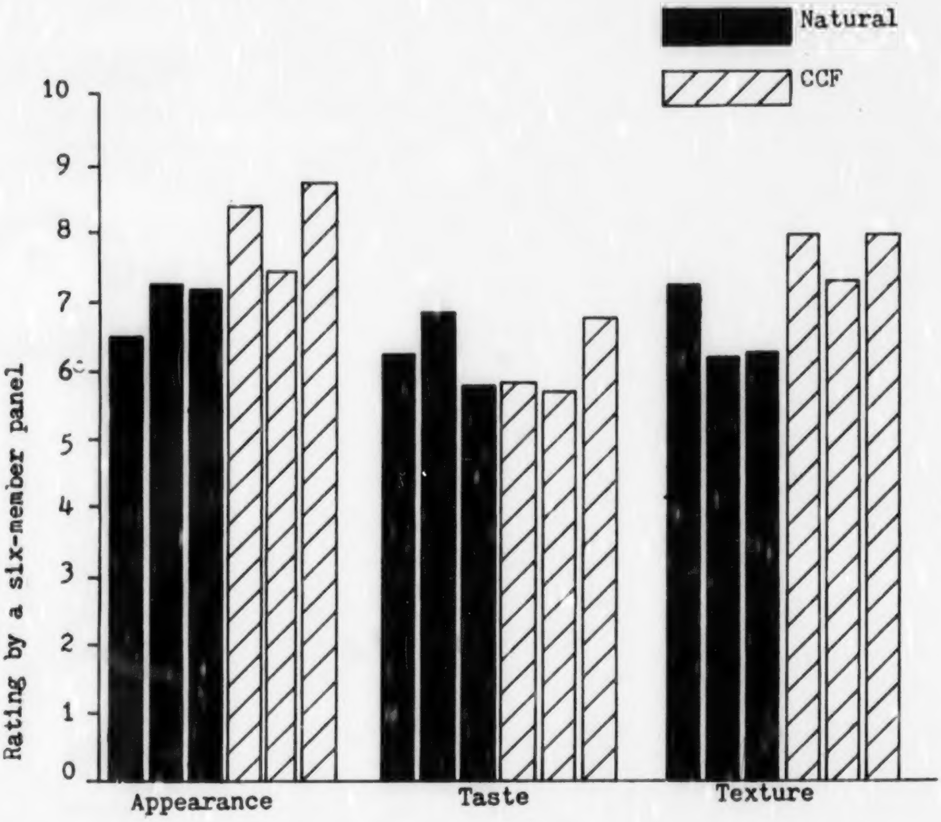
3. Etchells, J. L., Bell, T. A., Fleming, H. P., Kelling, R. E., and Thompson, R. L. Suggested procedure for the controlled fermentation of commercially brined pickling cucumbers -- the use of starter cultures and reduction of carbon dioxide accumulation. *Pickle Pak Science 3*: 4 (1973).

4. Fleming, H. P., Thompson, R. L., and Bell. T. A. Quick method for estimating CO_2 in cucumber brines. Advisory statement from the U.S. Food Fermentation Laboratory, Agricultural Research Service, USDA, Raleigh, N. C. (1974).



Average ratings:	Appearance	Taste	Texture
NF	8.2	7.4	7.6
CCF	8.3	7.2	7.4

Figure 2. Evaluation of hamburger chips prepared by natural fermentation (including a commercial product) and by controlled culture fermentation.



Average ratings:	Appearance	Taste	Texture
NF	7.0	6.3	6.9
CCF	8.2	6.1	7.8

Figure 3. Evaluation of whole dill pickles prepared by natural fermentation and by controlled culture fermentation.

TABLE 3. NATURAL FERMENTATION COMPARED TO CONTROLLED CULTURE FERMENTATION: COMPARISON OF VOLUME OF WASTEWATER AND AMOUNT OF SALT TO BE WASTED

		Spent Brine		1st Process Water		2nd Process Water		Total	
Type	Expt.	Vol (1)	Salt (10^3g)	Vol (1)	Salt (10^3g)	Vol (1)	Salt (10^3g)	Vol (1)	Salt (10^3g)
NF	I	1575	212.6	790	63.2	----	----	2366	275.8
	II	1285	173.5	200	12.5	1040	65.0	2525	251.0
		1015	142.0	200	14.8	1060	72.3	2275	229.1
	III	1350	145.8	1260	89.5	----	----	2610	235.3
								Average	248
CCF	I	1230	102.6	770	39.2	----	----	2000	141.8
	II	1190	102.3	1350	50.1	----	----	2540	152.4
		1250	99.7	1255	45.2	----	----	2505	144.9
	III	1180	111.6	850	53.1	----	----	2030	164.7
		1170	79.6	885	44.2	----	----	2055	123.8
								Average	146

5. Etchells, J. L. Bell, T. A., Fleming, H. P., Kelling, R. E., and Thompson, R. L. Bloater chart. Published and distributed by Pickle Packers International, Inc., St. Charles, Ill. (1974).

6. Fleming, H. P., Thompson, R. L., Bell, T. A., and Monroe, R. J. Effect of brine depth on physical properties of brine-stock cucumbers. In press.

SALMON PROCESSING WASTEWATER TREATMENT

by

P. A. Bissonnette*, S. S. Lin*, and P. B. Liao*

INTRODUCTION

The Skokomish salmon processing plant was built to provide a more efficient system for handling fish from the Indian commercial fishery on the Skokomish River. It is located on the Olympic Peninsula near the mouth of the Skokomish River about 45 miles southwest of Seattle, Washington (Figure 1). The processing plant was designed in 1971, constructed in 1972, and has been in operation since December, 1972. It consists of a fish preparation area where salmon are hand-butchered and cleaned, smokehouses, refrigeration/freezing capacity, and a retail outlet (Figure 2). The processing plant is capable of processing 590 lb/hr for yearling salmon and 2,000 lb/hr for large salmon.

In order to comply with regulatory requirements, the wastewater treatment facility was constructed in conjunction with the processing plant in April, 1975, and a water quality monitoring program was initiated in September, 1975, to evaluate its performance. The treatment facility consists of an extended aeration system and two identical aerobic polishing ponds. The rational used for the design of the treatment facility was based on literature review and characteristics of the waste as determined by daily grab samples. The literature review was limited since very little has been published on the characteristics of salmon processing wastes. The EPA effluent guidelines for salmon processing wastes were also developed based on this same small data base. The objectives of this study were to evaluate the EPA recommended effluent limitation guidelines with respect to the extended aeration treatment process and to develop more reliable design criteria.

CHARACTERISTICS AND TREATABILITY OF SALMON PROCESSING WASTES

A complete literature review for fresh-frozen processing wastes is reported in an earlier paper(1). In general, little has been published about the characteristics of waste generated by salmon processing and its treatability. Possibly the most reliable data for salmon processing wastes was provided by a seafood waste survey(2) of six plants in Alaska and one in the Northwest. Table 1 summarizes the waste loads from all hand-butchered salmon processes studied during the survey.

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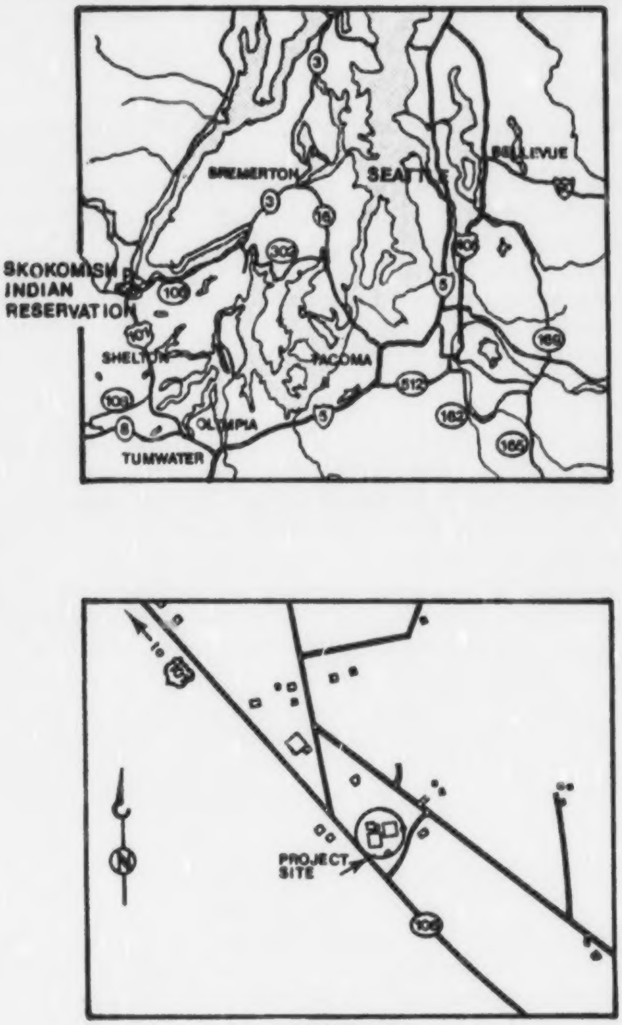
*Kramer, Chin & Mayo, Inc., Consulting Engineers, Architects and Applied Scientists, 1917 First Avenue, Seattle, Washington.


BREMERTON
SEATTLE
BELLEVUE
SKOKOMISH
INDIAN
RESERVATION
SHELTON
TACOMA
OLYMPIA
TUMWATER
3
3
16
302
106
101
108
8
5
5
405
169
512
162
165
90
101
PROJECT
SITE
106
N

VICINITY MAP

FIGURE 1 LOCATION AND VICINITY MAPS
SKOKOMISH PROCESSING PLANT
SHELTON, WASHINGTON

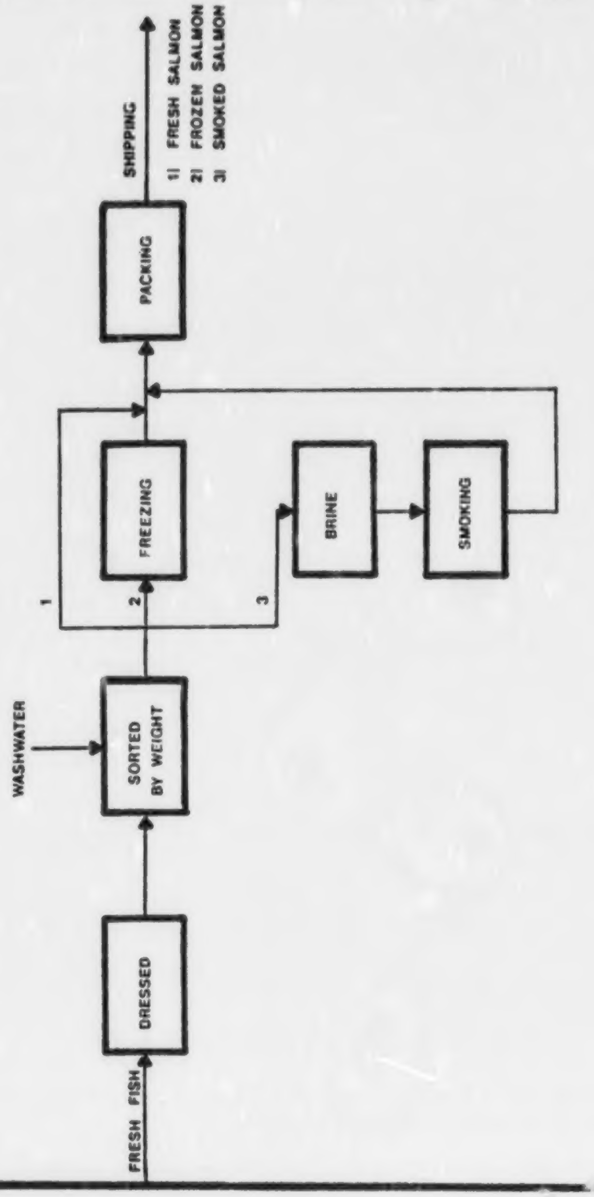

FRESH FISH
DRESSED
WASHWATER
SORTED BY WEIGHT
1
2
3
FREEZING
BRINE
SMOKING
PACKING
SHIPPING
1) FRESH SALMON
2) FROZEN SALMON
3) SMOKED SALMON

FIGURE 2 PROCESS LAYOUT OF SKOKOMISH SALMON PROCESSING PLANT SHELTON, WASHINGTON

TABLE 1. HAND-BUTCHERED SALMON PROCESS SUMMARY*

Parameter	Mean	Std. Dev.	5% Min.	95% Max.
Production, ton/hr	2.13	1.09	0.733	4.38
Process Time, hr/day	6.34	1.80	3.67	8.98
Flow, l/sec	2.15	1.09	0.754	4.39
(gal/min)	34.1	17.2	11.9	77.5
Flow Ratio, l/kkg	5,040	3,100	1,410	13,000
(gal/ton)	1,210	743	338	3,120
Sett. Solids, ml/l	1.02	1.19	0.109	4.18
Ratio, l/kkg	5.15	5.99	0.547	20.5
Sol. Solids, mg/l	193	155	37.5	600
Ratio, kg/kkg	0.971	0.782	0.189	3.12
Sus. Solids, mg/l	236	185	47.6	722
Ratio, kg/kkg	1.19	0.933	0.240	3.54
5-Day BOD, mg/l	493	179	233	923
Ratio, kg/kkg	2.48	0.900	1.17	4.35
COD, mg/l	1,070	601	332	2,600
Ratio, kg/kkg	5.36	3.03	1.67	13.1
Grease/Oil, mg/l	341	628	15.0	1,770
Ratio, kg/kkg	1.72	3.16	0.076	8.39
Organic-N, mg/l	80.9	40.0	29.0	181
Ratio, kg/kkg	0.407	0.202	0.146	0.314
Ammonia-N, mg/l	2.12	0.794	0.979	4.14
Ratio, kg/kkg	0.011	0.004	0.005	0.120
pH	6.73	0.318	6.25	7.13
Temp., degrees C.	13.2	2.51	9.19	15.7

---

*From Environmental Associates, Inc., "Draft - Canned and Preserved Fish and Seafoods Processing Industry," February 1974.

Various investigators have reported the success of using biological treatment for seafood processing wastes. In three studies(1)(2)(3) at least 80-90 percent removal efficiency of BOD was achieved. The success of the extended aeration process was dependent on controlled waste loadings.

The EPA effluent limitations guidelines for salmon processing plants are presented in Table 2.

TABLE 2. RECOMMENDED EFFLUENT LIMITATIONS GUIDELINES FOR SALMON PROCESSING PLANTS*(1)

PARAMETER	DAILY MAXIMUM kg/kkg	DAILY MAXIMUM lb/ton	MAXIMUM 30-DAY AVG. kg/kkg	MAXIMUM 30-DAY AVG. lb/ton
5-Day BOD	4.7	9.4	3.2	6.4
Total Suspended Solids	3.2	6.4	2.0	4.0
Grease and Oil	7.0	14.0	4.9	9.8

*Only for West Coast hand-butchered salmon.

THE SKOKOMISH WASTEWATER TREATMENT SYSTEM

The Skokomish processing plant's extended aeration treatment system, hereafter called the full-scale plant, was designed based on expected loadings from projected production at 2,000 lb/hr for large salmon and 590 lb/hr for yearling salmon. It was also projected by the Skokomish tribe that the processing plant would eventually double in capacity. Table 3 summarizes the actual production schedule since the project's initiation. The peak production period is July through October rather than September through January as projected. In fact, for the past two years no fish have been available for processing in January. The bulk of the fish processed during February through July are yearling salmon from a private fish supplier. The large salmon processed are generally those caught by members of the tribe.

Based on the projected production and literature values for hand-butchered salmon wastewater characteristics (Table 1), the extended aeration system was designed. Table 4 summarizes the design criteria, and Figure 3 shows a flow diagram of the facility.

The projected levels of incoming fish to process was not realized and the decrease in operations resulted in lower flows and longer retention times through the treatment facility than expected. A smaller scale extended aeration system was constructed a year later (September, 1976), hereafter called the pilot plant, to test lower retention times and higher loadings. Table 5 summarizes the design criteria for the pilot plant, and Figure 4 shows a diagram of the facility.

TABLE 3. SALMON PRODUCTION SCHEDULES FROM SEPTEMBER THROUGH FEBRUARY, 1977

Month		Monthly Total (lb)	Daily Average* (lb)	Size**
1975	September	78,382***	7,838	Large
	October	75,191	3,760	Large
	November	29,865	1,493	Large
	December	8,620	431	Large
1976	January	-0-	-0-	- - -
	February	49,800	2,490	Small
	March	64,570	3,228	Small
	April	-0-	-0-	Small
	May	38,350	1,918	Small
	June	34,070	1,704	Small
	July	59,890	2,994	Small
	August	150,350	7,518	Small/Large
	September	44,539***	4,454	Large
	October	94,176	4,709	Large
	November	22,548	1,127	Large
	December	28,050	1,402	Large
1977	January	-0-	-0-	- - -
	February	-0-	-0-	- - -

*Based on 20 working days per month and one shift per day.

**Large fish approximately 10 lbs; small fish approximately 11 oz.

***Value for last half of September.

TABLE 4. SUMMARY OF DESIGN, WASTEWATER TREATMENT FACILITIES

Waste Characteristics

Source = Process water, no sanitary waste
Minimum Flow = 0 gpd
Maximum Flow = 20,000 gpd
Peak Flow = 18 gpm
Daily Flow Variation = Continuous over approximately 18 hours
Average BOD Concentrations = 500 mg/1
Maximum BOD Loading = 80 lb/day

Extended Aeration System

Aeration Tank:
Volume = 20,000 gallons
Detention Time at Maximum Flow = 24 hours
Maximum Oxygenation Available = 240 lb O_2/day
Maximum Loading = 0.03 lb BOD/cu ft/day

Clarifier:
Volume = 3,000 gallons
Detention Time at Maximum Flow = 2.7 hours
Surface Area = 98 sq. ft.
Overflow Rate at Maximum Flow = 202 gpd/sq. ft.

Polishing Ponds

Surface Area = 0.37 acre
Loading at Maximum Flow = 21.5 lb BOD/acre/day
Volume = 364,000 gallons
Detention Time at Maximum Flow = 18 days

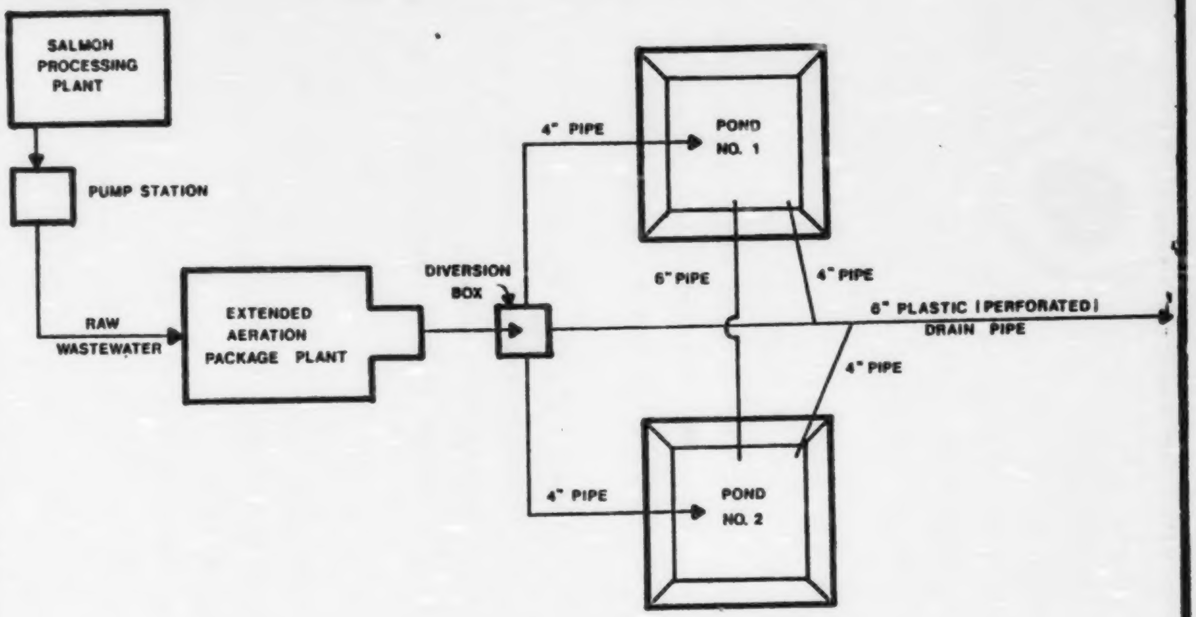

SALMON PROCESSING PLANT
PUMP STATION
RAW WASTEWATER
EXTENDED AERATION PACKAGE PLANT
DIVERSION BOX
4" PIPE
4" PIPE
POND NO. 1
POND NO. 2
6" PIPE
4" PIPE
4" PIPE
6" PLASTIC (PERFORATED) DRAIN PIPE

FIGURE 3. FLOW SCHEME OF THE WASTE TREATMENT SYSTEM
SKOKOMISH PROCESSING PLANT
SHELTON, WASHINGTON

TABLE 5. DESIGN CRITERIA FOR SKOKOMISH PILOT TREATMENT PLANT

Aeration Chamber

1) Dimension:
    - Diameter 15 ft.
    - Depth 4 ft.
    - Total Volume = 4,500 gal. @ 3.5 ft.
    - Each chamber has 2,250 gallons
2) Air supply roots frame No. 22 Blower - 14 cfm @ 3 psi
3) Chamber divider, plastic sheeting siliconed in place with baffles to equalize head.

Clarifier

Volume	135 gallons each
Surface area	6.25 ft^2 each
Compressor for slug return air lift pump	2.5 cfm @ 25 psi

Operation Conditions

Aeration Chamber -

Retention time 18 hr. ∿ 120 hr. (if flow > 2,250 gpd dual system will be in operation)

Clarifier -

Retention time 1.1 hr. ∿ 7.9 hr.

Overflow rate 6.5 ∿ 480 gpd/ft^2

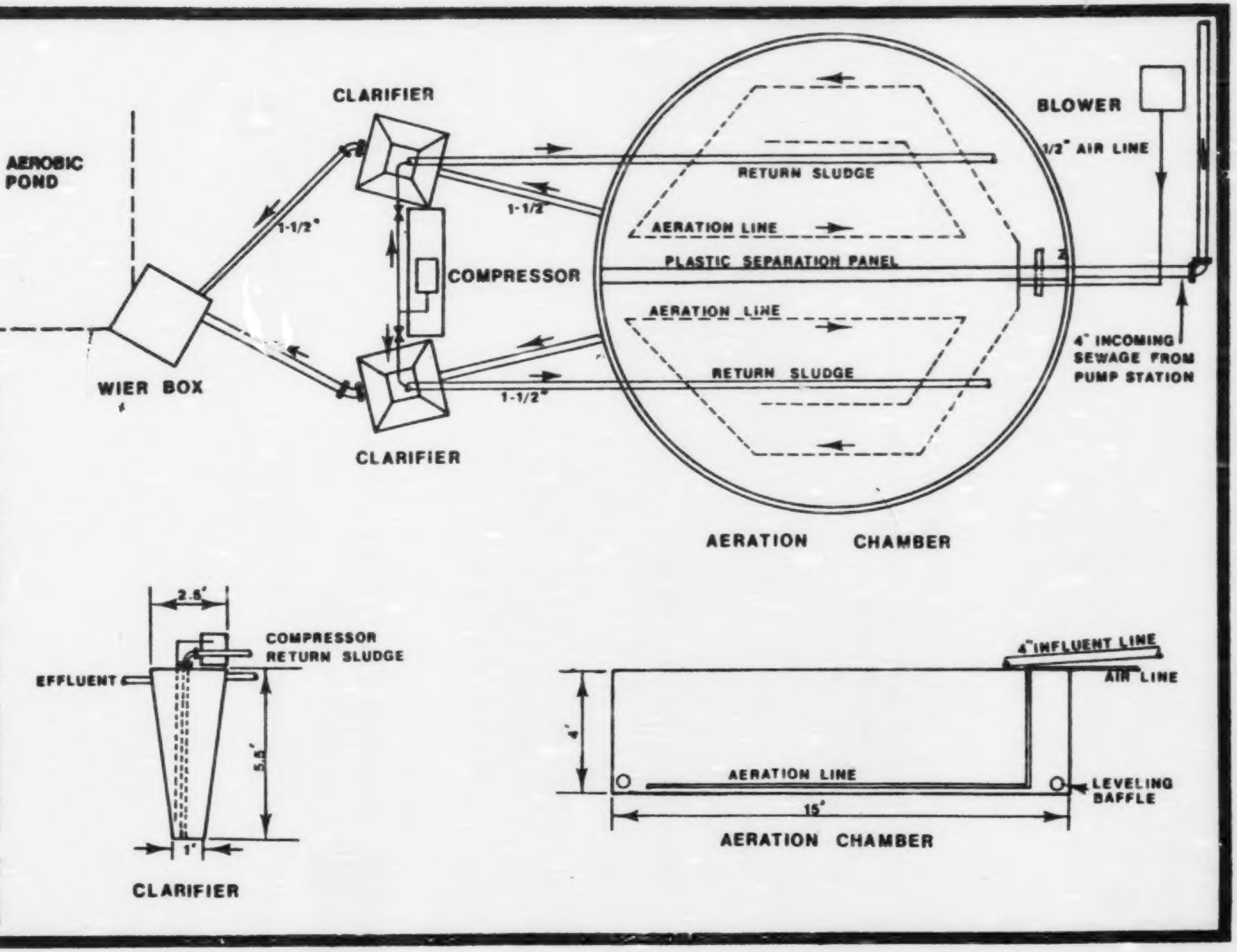

AEROBIC POND
WIER BOX
1-1/2"
CLARIFIER
COMPRESSOR
CLARIFIER
1-1/2"
1-1/2"
RETURN SLUDGE
AERATION LINE
PLASTIC SEPARATION PANEL
AERATION LINE
RETURN SLUDGE
BLOWER
1/2" AIR LINE
4" INCOMING SEWAGE FROM PUMP STATION
AERATION CHAMBER
2.5'
COMPRESSOR
RETURN SLUDGE
EFFLUENT
5.5'
1'
CLARIFIER
4" INFLUENT LINE
AIR LINE
4'
AERATION LINE
LEVELING BAFFLE
15'
AERATION CHAMBER

FIGURE 4: SKOKOMISH PILOT TREATMENT PLANT

WATER QUALITY MONITORING PROGRAM

Eight sampling sites were originally chosen to characterize the different stages of the treatment process. In addition, two different treatment schemes were planned involving the aerobic ponds. Both the sampling locations and treatment schemes are shown in Figure 5.

Sampling Stations	Location
a	Incoming raw wastewater
b	Aeration tank
c	Return sludge and excess sludge pipe
d	Effluent of extended aeration process
e	Aerobic Pond No. 1
f	Aerobic Pond No. 2
g	Effluent of Aerobic Pond No. 1
h	Effluent of Aerobic Pond No. 2

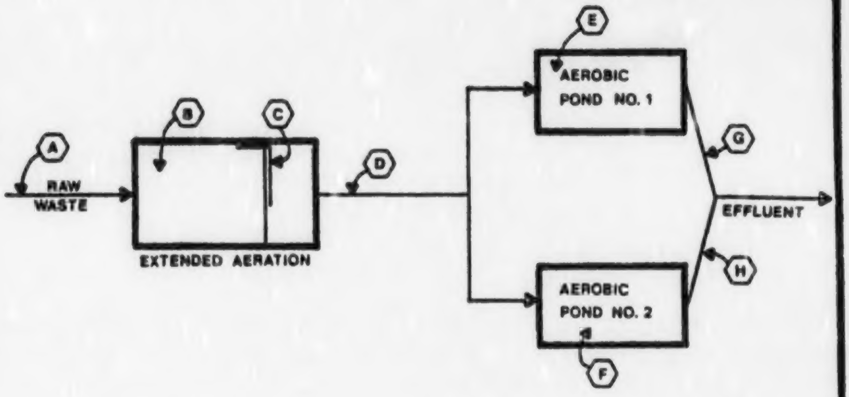
All chemical and biological sampling, preservation, and tests were analyzed in accordance with Standard Methods(4) and EPA Manual of Methods(5). Field tests included flow, pH, DO and temperature. Laboratory analysis included BOD and COD (both total and soluble), settable solids, SS, VSS, TS, grease and oil, TKN, alkalinity, turbidity, ortho-P, total-P, MLSS, and MLVSS for the most part. Table 6 summarizes the daily sampling and analysis. Throughout most of the study, sampling days averaged 3 days every two weeks.

Due to difficulties in obtaining fish to process during parts of the study (see Table 3) the monitoring program was extended and is now scheduled for completion during summer, 1977. Currently, monitoring of the pilot plant continues.

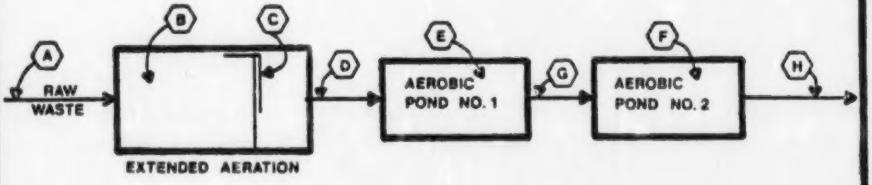
RESULTS AND DISCUSSION

The aeration chamber of the full scale plant was seeded with 1,000 gallons of 4,500 mg/l returned activated sludge from a large municipal treatment plant at the project initiation. Water meters were installed for continuous recording of water consumption during fish processing. Wastewater from fish processing was pumped to the treatment facility after fine screening, and sanitary wastes were conveyed to a septic tank for treatment. Based on pumping duration and rate, the flow entering the extended aeration system was computed. A weir box was installed at the aerobic pond to record the flow rate of effluent from the extended aeration system.

Processing of small yearling salmon and large salmon account for most operations throughout the year and generated most of the wastes entering the treatment system. Small salmon herin refers to an average weight of 11 ounces per fish and large salmon refers to an average weight of 10 pounds per fish. Large salmon are generally processed from August through July. During periods, such as January, when no processing wastewater is generated, the extended aeration system was maintained by feeding approximately 9.5 pounds of Purina Trout Chow dissolved in 560 gallons of water into the pump station.


A
RAW WASTE
B
C
EXTENDED AERATION
D
E
AEROBIC POND NO. 1
AEROBIC POND NO. 2
F
G
H
EFFLUENT

SCHEME A


A
RAW WASTE
B
C
EXTENDED AERATION
D
E
AEROBIC POND NO. 1
G
F
AEROBIC POND NO. 2
H

SCHEME B

FIGURE 5 PROCESS LAYOUTS

TABLE 6. DAILY SAMPLING SCHEDULE

Sampling Stations	Sampling Frequency	Tests
a	Grab Samples/2 hour	Flow, Temp, pH, DO
	Eight-hour Composite	BOD, COD, SS, VSS, TS, Grease/Oil*, TKN, Ortho-P, Total P, Alkalinity, Turbidity
c	One Grab Sample Daily	MLSS, MLVSS, DO, Alk., pH, Temp.
d	Same as (a)	Same as (a) (Flow measurement is not necessary)
e	One Grab Sample Daily	DO, pH, Temp.
f	Same as (e)	Same as (e)
g	Same as (d)	Same as (d)
h	Same as (d)	Same as (d)

*One grab sample for sampling day.

Monitoring during fish food addition indicated wastewater characteristics comparable to those during salmon processing, and the performance of the treatment system was maintained when receiving no fresh fish processing wastewater.

Wastewater characteristics for large and small salmon are summarized and compared in Table 7. Approximately 20 percent of the total weight of fish processed was wasted. The wastage was hauled away to a sanitary landfill for disposal. Comparison of the wastewater characteristics showed that flow and the weight of pollutants generated per ton of fish processed for small salmon were greater than for large salmon. Conversely, pollutant concentrations generated during small fish processing were generally less than during large fish processing, which produced a stronger waste. As indicated by the standard deviations, the incoming wastewater in both cases was highly variable.

Also shown in Table 7 are the wastewater characteristics for large salmon processing as influent to the pilot plant. To date, no small salmon processing wastewater has been treated by the pilot plant. This is scheduled for the next phase of the study. Wastewater to the pilot plant was even more concentrated than for previous large salmon processing, which averaged 579 and 723 gallons of wastewater per ton of fish processed for the pilot and full-scale plants respectively. As a result, pollutant concentrations were greater for the pilot plant. Loadings were intermediate between those for large and small fish at the full-scale plant.

The processing plant receives returning adult chinook, chum and coho salmon. Generally chinook are the largest and coho the smallest in size. The 1976 adult returns contained a larger proportion of the smaller fish than for 1975. In addition, wastewater in the storage bins, which in 1975 was washed into the septic tank, was released to the extended aeration system in 1976. These two phenomena may account for higher pollutant loadings during 1976 for large fish processing.

Comparison of Table 7 to Table 1 indicates pollutant concentrations from the Skokomish processing plant were generally higher than for those surveyed, although on the average the gallons of wastewater generated per ton of fish processed were about equal (1,210 gal/ton for those surveyed versus 1,223 gal/ton average for the Skokomish plant). Loadings were similiar for large fish processing, but higher for small fish processing than those surveyed.

Operating conditions for both plants are summarized in Table 8. Because the projected numbers of fish were not realized, retention times and DO concentrations were high, but F/M (food-to-microorganism) ratios were within the range of 0.05 to 0.2 recommended for the extended aeration process.(6) Processing times were about one-third the expected. The higher flows associated with processing small fish reduced the retention time to seven days in the full-scale plant. The change-over to the pilot plant occurred coincident with a switch to processing large salmon, and the consequent reduction in flows resulted in a retention time of five days. During the last phase of the project, wastewater from small salmon processing will be treated in the pilot plant, and sufficient flows are expected to test retention times of fractions of one day.

TABLE 7. WASTEWATER CHARACTERISTICS FOR THE SKOKOMISH SALMON PROCESSING PLANT

Parameter	1975 Full-Scale Plant Large Salmon Average	 Standard Deviation	1976 Small Salmon Average	 Standard Deviation	1976 Pilot Plant Large Salmon Average	 Standard Deviation
Flow, gpd	691	237	3,143	1,001	601	308
Process Time, hr/day	6.5	1.0	5.4	1.3	4.9	11.39
Fish Processed, lb/day	3,153	2,658	2,751	812	4,003	3,561
Processing Wastage, lb/day	747	614	570	170	807	700
Gallon of Wastewater per Ton of Fish Processed	723	599	2,366	764	579	603
Turbidity, JTU	100	49	60.8	44.2	145	60.8
pH	7.2	0.1	7.1	0.2	7.1	0.2
DO, mg/1	7.9	1.0	7.3	1.7	6.1	2.3
Temp., degrees F.	51.5	3.6	52.5	2.3	56.7	5.4
Alk., mg/1 as $CaCO_3$	128	88	49	7	94	8
BOD (total), mg/1	687	445	665	273	1,664	650
BOD (total), lb/ton	3.26	2.50	10.36	5.29	5.68	4.44
COD (total), mg/1	2,057	1,120	902	398	2,009	780
COD (total), lb/ton	10.5	8.6	13.9	6.4	7.9	6.6
BOD/COD (total)	0.33	0.10	0.70	0.12	0.82	0.11
SS, mg/1	502	224	320	479	760	342
SS, lb/ton	2.5	1.4	4.4	3.3	3.6	4.2
VSS, mg/1	265	147	225	405	607	247
VSS, lb/ton	1.3	0.9	2.6	2.0	2.9	3.3
VSS/SS	0.541	0.175	0.703	0.192	0.810	0.065
TS, mg/1	1,638	861	1,029	650	1,679	508
TS, lb/ton	7.5	2.8	15.8	8.2	7.6	8.2
Grease and Oil, mg/1	283	142	859	372	603	269
Grease and Oil, lb/ton	1.5	0.9	4.3	2.2	3.7	5.4
TKN, mg/1	207	197	73	50	52	24
TKN, lb/ton	0.86	0.49	1.08	0.78	0.20	0.15
NH_4 ± N, mg/1	6.04	7.25	4.67	3.20	7.68	1.89
NH_4 ∓ N, lb/ton	0.04	0.04	0.30	0.32	0.04	0.05
Total-P, mg/1	0.26	0.16	0.56	0.35	0.67	0.44
Total-P, lb/ton	0.0020	0.0027	0.0085	0.0065	0.0065	0.0092
Ortho-P, mg/1	0.11	0.05	0.49	0.23	0.51	0.34
Ortho-P, lb/ton	0.0007	0.0007	0.0052	0.0036	0.0059	0.0042

TABLE 8. OPERATING CONDITIONS FOR THE EXTENDED AERATION FACILITIES

Parameter	Full Scale Plant				Pilot Plant	
	Large Salmon		Small Salmon		Large Salmon	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Retention Time (days)	31	8	7	2	6	5
Processing Time (hrs/day)	6.5	1.0	5.4	1.3	4.9	1.4
pH	7.3	1.0	7.1	0.4	7.1	0.4
DO (mg/1)	8.3	1.4	5.7	1.5	2.0	1.3
SVI	151	24	129	28	153	30
F/M	0.06	0.06	0.05	0.04	0.21	0.16
MLVSS	516	174	1,015	433	2,011	469
MLSS	978	218	2,240	666	2,498	771
MLVSS/MLSS	53%		45%		83%	
Overflow Rate (gal/processing period/square foot	38	22	173	105	243	99

Even though the flow rate through the aeration chamber was low, the clarifier for the new system experienced some bulking due to undersizing. This problem has been corrected. No samples were taken when bulking was evident.

The percentage of MLVSS to MLSS responded to organic loading. At the full-scale plant, the volumetric loading was 2 lb BOD_5/1,000 cu ft and 7 lb BOD_5/ 1,000 cu ft on the average for large and small salmon respectively. This increased to 30 lb BOD_5/1,000 cu ft for the pilot plant. Both the full-scale and pilot plants exceeded the recommended range of 10 to 25 lb BOD_5/1,000 cu ft for extended aeration.(6)

Table 9 summarizes the extended aeration treatment efficiencies for the processing wastewater. Comparing large and small fish at the full-scale treatment facility, removal efficiencies for most parameters were not appreciably different except for nutrients. Ammonia and TKN removal efficiencies were twice as high for the large fish which was probably due to the higher incoming concentrations (see Table 7) and longer retention times causing some denitrification. Conversely, the removal efficiencies of TP are about 50 percent lower for large fish and may have been due to over aeration (longer retention time) causing the release of phosphate in the aeration chamber.(7)

Comparing large fish processed at the full-scale and pilot plants, removal efficiencies for BOD, COD, TKN, and ammonia were similar. However, the removal efficiencies for solids, grease/oil and phosphorus increased dramatically. Reasons for increased removal of phosphorus are discussed above. Improvements in removal efficiencies for solids and grease/oil are probably due to higher incoming concentrations and shorter retention times. During full-scale plant operations effluent turbidity was approximately 30 percent higher even though the clarifier overflow rate was lower, and a yellowish-brown color was noticeable which disappeared with change-over to the pilot plant. It is suspected that the longer retention times at high DO concentrations favored filamentous growths in the full-scale plant. Apparently, filamentous microorganisms which have poor settling characteristics are able to utilize slowly the inert polysaccharide material produced by the bacteria, giving the filamentous forms a source of food that is unavailable to bacteria.(8) However, this is inconsistent with the sludge volume indexes (SVI) which showed the pilot plant to have essentially identical sludge settling characteristics to the full-scale plant during large fish processing and a higher SVI during small fish processing (Table 8). This problem will be further investigated during the next phase of the study.

Because of the low flows through the extended aeration system and the high permeability of the soils in the aerobic ponds, no effluent has been discharged, or analyzed, from the ponds. Therefore, the two treatment schemes of the ponds in parallel or succession could not be tested.

Oxygen uptake for mixed liquor suspended solids (MLSS) was tested in the field using a YSI DO probe. Only data from the full-scale plant is currently available and is summarized as follows.

Average 1.59 mg/l/hr - Standard Deviation 0.55 mg/l/hr - Range 0.8-2.5 mg/l/hr

TABLE 9. EXTENDED AERATION TREATMENT EFFICIENCIES FOR SALMON PROCESSING WASTEWATER

	Full Scale Plant				Pilot Plant	
	Large Salmon		Small Salmon		Large Salmon	
Parameter	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
BOD, %	91	8	91	5	93	5
COD, %	88	5	82	14	89	8
SS, %	62	18	52	32	93	3
VSS, %	66	20	47	36	93	3
TS, %	45	19	46	36	65	14
Grease and Oil, %	69	19	55	20	82	17
TKN, %	83	16	46	31	89	7
$NH_4 \pm N$, %	72	24	37	29	68	13
Total-P, %	28	3	58	43	43	24
Ortho-P, %	37	25	N/A**	N/A**	53	26

**N/A indicated that effluent concentrations were either greater than or equal to influent.

Additional data will be collected during the next phase of the study to be used in developing design criteria.

To date, no sludge has been wasted. A sludge filterability test was conducted to indicate sludge dewatering characteristics. One-hundred milliliters of sludge was filtered under a pressure of 21 psi for 80 minutes, and solids concentrations were measured at 0, 20, 40, 60, and 80 minutes. These results are compared in Table 10. Percentage of SS increase were similar for both large and small fish processing at the full-scale plant and slightly higher for the pilot plant.

Table 11 compares the extended aeration effluent quality with EPA effluent limitations. In all cases the average and maximum extended aeration effluent loadings were below the EPA limits. The lowest loadings resulted from the pilot plant operation. Small salmon processing effluent had the highest loadings as would be expected from the high influent loadings.

As stated previously, this study is still underway. The final phase is expected to be completed by mid-summer, 1977 and the final report should be published shortly thereafter.

CONCLUSIONS

Wastewater characteristics for salmon processing showed flow and pollutants generated per ton of fish processed for small salmon to be greater than for large salmon; conversely, waste strength was higher for large salmon. Incoming wastewater flows and concentrations were highly variable in both cases. Pollutant loadings from the Skokomish plant were similar for large fish processing, but generally higher for small fish processing than for others surveyed in the Northwest and Alaska.

Unexpected low flows resulted in long retention times and over aeration in the full-scale plant. The pilot plant achieved much lower retention times, (5 days versus 31 days), lower DO (2 mg/l versus 8 mg/l), and higher F/M ratios (0.2 versus 0.06).

Removal efficiencies for small fish processing were similar to those for large salmon processing except for nutrients. Higher removal efficiencies for nitrogen and lower removal efficiencies for phosphorus during large fish processing were the result of longer retention times and over aeration which may have caused some denitrification and phosphorus release in the aeration chamber.

Pilot plant removal efficiencies were similar for BOD, COD, TKN and ammonia, but higher for solids, grease/oil, and phosphorus. Shorter retention time and reduced aeration is the suspected cause, but more data is needed to confirm this result.

During long periods of processing plant shutdown, addition of fish food was found to maintain performance of the wastewater treatment system.

The treatment system is capable of producing an effluent which meets the EPA effluent limitations in terms of BOD, SS and grease/oil.

TABLE 10. COMPARISON OF SLUDGE FILTERABILITY FOR THE SKOKOMISH EXTENDED AERATION FACILITY

	Pressure (psi)	Initial Concentration mg/1	Time (min)	Percentage of SS	
				Increase	Range
Skokomish Study					
Full Scale Plant					
Large Fish	21	1370	20	122	116-126
Small Fish	21	2730	20	124	116-135
Pilot Plant					
Large fish	21	2117	20	134	123-150

TABLE 11. COMPARISON OF EXTENDED AERATION EFFLUENT QUALITY WITH EPA EFFLUENT LIMITATIONS

	Average Weight of Fish Processed (ton/day)	EPA Effluent* Limitations (lb/day)	Extended Aeration Effluent Quality (lb/day)	
			Average	Range
Full Scale Plant				
Large Salmon	1.58			
BOD, lb/day		10.1	0.4	0.03-1.3
SS, lb/day		6.3	1.5	0.3 -3.0
Grease/Oil, lb/day		15.5	0.7	0.1 -1.2
Small Salmon	1.38			
BOD, lb/day		8.8	1.3	0.04-3.5
SS, lb/day		5.5	1.7	0.48-2.7
Grease/Oil, lb/day		13.5	2.3	0.47-10.0
Pilot Plant				
Large Salmon	2.00			
BOD, lb/day		12.8	0.5	0.2-1.3
SS, lb/day		8.0	0.3	0.1-0.9
Grease/Oil, lb/day		19.6	0.4	0.1-1.3

*Based on maximum 30-day average (see Table 2)

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REFERENCES

1. LIN, DR. S. S. and DR. P. B. LIAO. Evaluation of an extended aeration process for salmon processing wastewater treatment. Presented at the PNPCA Industrial Waste Conference, Seattle, Washington, October 28, 1976.

2. ENVIRONMENTAL ASSOCIATES, INC. FOR U.S. EPA. Draft development document for effluent limitations guidelines and standards of performance - canned and preserved fish and seafoods processing industry. February, 1974.

3. RIDDLE, M. J. et al. An effluent study of a fresh water fish processing plant. Water Pollution Control Directorate Reprint EPT G-WP-721, Canada, 1972.

4. STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. American Public Health Association, 13th Ed., 1971.

5. MANUAL OF METHODS FOR CHEMICAL ANALYSIS OF WATER AND WASTES. U.S. EPA, Office of Technology Transfer, Washington, D.C., 1974.

6. METCALF & EDDY. Wastewater Engineering: Collection, Treatment, Disposal. McGraw-Hill Series in Water and Environmental Engineering, 1972.

7. SEKIKAWA, Y., et al. Release of solubale ortho-phosphate in the activated sludge process. Kurita Central Laboratories, Yokohama, Japan.

8. McKINNEY, ROSS E. Microbiology for Sanitary Engineers. McGraw-Hill Book Company, Inc., New York, 1962.

FUNGAL CONVERSION OF CARBOHYDRATE WASTES TO ANIMAL FEED PROTEIN-VITAMIN SUPPLEMENTS

by

Brooks D. Church*, Charles M. Widmer**, and Rudolpho Espinosa***

The purpose of these studies was to establish an inexpensive, low technology, continuous industrial method for the fungal conversion of corn wet-milling wastes to an animal feed protein-vitamin supplement and, concomitantly, to affect a significant BOD_5 reduction of the industrial plant processing wastes.

Sukhatme's (1) data suggests that while protein is not limiting in some of the world's population provided enough calories are available to permit efficient utilization of the protein, it is also clear that many regions are acutely deficient in protein but have abundant supplies of carbohydrate. The developed countries also have abundant supplies of carbohydrate from agricultural and industrial food processing amounting to approximately 400 million tons per year in the U.S. alone (2).

Although the studies described here were designed specifically for the bio conversion of corn wet-milling wastes to animal feed protein, the implications of the work are broader than that however, since the process has been extended to other waste substrates, has excellent industrial waste pre-treatment utility, and the product might ultimately find use as a human food.

BACKGROUND

The industrial cereal grain wastes used in all these studies were generated from Penick and Ford, Ltd., a subsidiary of Univar Co.. Penick and Ford is a corn wet miller producing corn dextrose syrup and starches for a variety of industries. The corn waste liquid streams arise as a result of steeping, washing, grinding, fractionation, and product purification. The different waste constituents used as fermentation substrates in these studies included corn syrup, starches, gluten, and steep liquor separately and mixed in various proportions. The total mixed liquor waste stream from this plant is approximately 3×10^6 gallons per day containing 0.3 to 0.7 percent dry solids.

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On the premise that there is and will continue to be a world protein shortage, many university and industrial research teams have put forth a large effort exploring the potential of single cell protein (SCP) as a novel protein source. In the course of this work, a wide variety of other carbon-energy sources also have been considered for use in protein production. The cost for the carbon source represents a major fraction of the protein production cost and may account for 40 to 50 percent (3). Utilities may represent typically 15 to 20% mostly as cost of power for oxygen transfer and heat removal. Although much attention has been given to hydrocarbon conversion to protein, particularly n-alkanes and more recently methanol; we believe waste carbohydrates of zero to a minus cost value emanating from the agro-industrial food areas represent the most ideal substrates. Ideal substrates for bioconversion because industry must otherwise allocate funds for their removal and because these carbohydrates are rapidly metabolized by a variety of high protein producing microorganisms. As a consequence of all these SCP studies, a number of large SCP plants are presently in operation and several more under construction (4). Therefore, we are no longer talking about a protein source of the future, but rather a protein source in use today (5).

Fungi used in bioconversion of carbohydrate waste substrates are the vegetative mycelium usually of species of Pencillium, Aspergillus, Trichoderma, and Gliocladium. The fungi used in these and other studies grow over a wide range of pH (2.5 to 5.0), and are rich in the B-group of vitamins and contain 40 to 55 percent protein. They contain low nucleic acid levels of approximately 4 to 6 percent and have a protein conversion efficiency from a given quantity of carbohydrate of about 50 percent which is far superior to the 4, 5, 15, and 20 percent efficiencies for protein production by beef, poultry, milk and pork respectively. Other advantages the fungi have compared to bacteria, algae, and yeast are: simplicity of process fermentation, utilization of zero to minus value waste substrates for growth and nutrition, flexibility of the fungal biomass to maintain its dominant cultural position in the face of other microbial contaminants and process malfunctions, its generally favorable process economics for protein production, and lack of toxicity in numerous animal feeding trials (6,7,8,9). Therefore, the use of fungal microorganisms to relieve the global protein shortage can be accomplished rather safely and economically. The major problems remaining are probably psychological and adequate funding for conducting large scale feeding trials to meet quality standards.

Industrial waste treatment studies employing a variety of fungal strains have been conducted over the past 5 to 8 years (5,6,7, and 12). In general, the results have demonstrated an 80 to 95 percent reduction of the plant processing BOD_5 waste. Short retention times of 6 to 8 hours have been experienced where the waste substrates were chiefly sugars (glucose, lactose, and sucrose) and longer times of 10 to 15 hours with starches. A very short retention time of 4.5 to 5 hours is realized by the Finnish workers (7) using waste streams from the pulp and paper industries. They anticipate a protein production of approximately 10-15 thousand tons a year from their "Pekilo" process. These are all continuous fermentation processes and several have been in operation for over four years.

METHODS

Laboratory Studies

Screening and selection of the most desirable fungal strains were based on two criteria: a high fungal protein content and the fungal ability to rapidly metabolize the raw waste substrates. In the case of corn wet milling wastes, described here, two fungi best met these criteria: Trichoderma viride, I-23 and Gliocladium deliquescens, I-31. The two fungal strains were maintained on potato-dextrose agar slants. At time of experimental start-up, a slant was used to inoculate 50 ml. sterile potato dextrose broth. After 24 hours, 5 ml. of the potato dextrose fungal culture was used to inoculate the 50 ml. sterile corn waste medium (2nd transfer). After another 24 hours, 50 ml. from the 2nd transfer culture was used to inoculate 1000 ml. of non-sterile corn waste medium. All culture transfers were made in shake flasks and incubated at room temperature on a mechanical shaker. The final or 3rd transfer culture (1000 ml.) was added to the 15 liter fermentor which contained 5 l of waste substrate and 10 l of water. The design and operation of the fermentation process was such as to maintain the fungal biomass in the vegetative mycelial state at all times. Certain deviations from this fungal morphocytogenetic state, e.q. sporulation, indicated plant process malfunction. The altered fungal forms often constituted valuable indicators of fermentation malfunction which called for specific equipment and nutrient adjustment. Morphogenetic changes in the fungal biomass were determined by frequent rapid phase microscopic observations of the effluent material.

The waste carbohydrate substrates used in the laboratory studies were composed of 66 percent corn starch, 33 percent corn dextrose, and 1 percent heavy corn steep liquor (51% solids). This same waste substrate ratio was not always maintained in the pilot and full scale processes. When substrate alterations occurred in the plant waste effluent stream (influent to the waste treatment process), adjustments to restore optimal nutrient conditions were quickly made via nutrient additions or deletions usually in the form of corn steep liquor, urea, and inorganic phosphate. Chemical analyses were made on frequent grab and composite samples from both the influent waste substrate and the effluent fermentation liquor. No sterilization of the waste substrates was ever conducted in the laboratory, pilot, or full scale fermentations after the second stage of inoculum build-up.

Fermentation design and equipment used in the laboratory studies, were described previously (5) and are shown here in Figure 1. This apparatus evolved from the author's original prototype in 1968 (11) to what now appears in Figure 1. It has proved to be extremely flexible for use both as a batch and as a continuous type fermentor. Later fermentor modifications include a battery of 4 fermentor units which can be operated individually, jointly, or in series. The design is such that only minimal amounts of fungal solids adhere to the internal surfaces. Sparged air introduced at the fermentor bottom, serves the dual prupose of providing oxygen as well as continuous mixing of the fermentation materials. The influent substrates drip onto the top surface of the mixed fermentation liquor

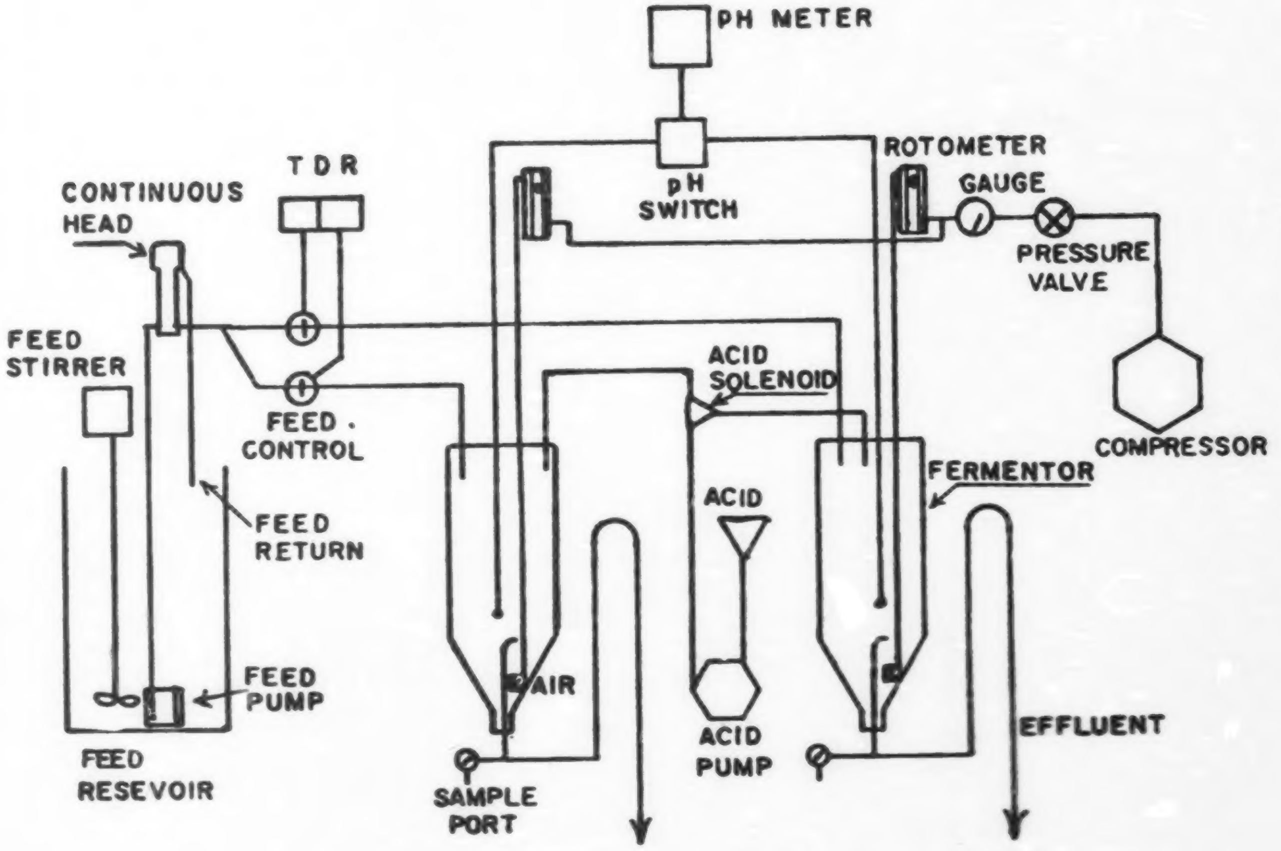

PH METER
pH SWITCH
ROTOMETER
GAUGE
PRESSURE VALVE
COMPRESSOR
CONTINUOUS HEAD
T D R
FEED STIRRER
FEED . CONTROL
FEED RETURN
FEED PUMP
FEED RESEVOIR
ACID SOLENOID
ACID
ACID PUMP
FERMENTOR
AIR
SAMPLE PORT
EFFLUENT

Figure 1. Laboratory Continuous Fermentation System.

thus allowing removal of the influent line as an internal fungal adhering surface which was present in our earlier fermentors. At the same time the effluent port was relocated to the bottom of the fermentor for continuous effluent discharge or for intermittent sample taking. This modification avoided any chance of "short circuiting" undigested waste substrates as was the case where effluent takeoff was located at the top surface level of the fermentor (11). In addition, the bottom effluent port allowed installation of a flexible effluent conduit which served, by simply raising or lowering the conduit, to vary the fermentor volume and thus adjust the dilution rate and retention time without adjusting the feed flow rate. The most recent modification to the system, not shown here, was to admit the air up through the bottom port. This releocation of the air line removed the last remaining permanent internal fungal adhering tube surface. Many of the 15 liter laboratory fermentor features were incorporated into the 50,000gal. pilot and the 3 x 10^{6}gal. full scale plants. Fermentor process control parameters e.q. pH, temperature, flow rate of waste substrate influent, oxygen, and added nutrient were recorded continuously onto standard recorder charts.

Pilot Plant Process

Individual processing steps of the continuous pilot fungal treatment process are shown in Figure 2. The total mixed plant waste stream was split to supply the fraction required for the pilot operation and flowed into a polyethylene lined concrete rectangular (74 ft. x 14 ft. x 10 ft) 190 m^3 tank at a flow rate of approximately 35 gallon/min. A minimal volume of hydrochloric acid was added to maintain the proper pH of 4.2 to 4.5. Nutrients such as heavy corn steep liquor (51% solids diluted 3-fold to facilitate pumping), urea, and sodium dihydrogen phosphate were added as required to maintain the desired nitrogen and phosphate concentrations. Air was supplied by two 40 H.P., 800 ft. /min. Roots-Connerville blowers. Air was blown into six-inch pipe headers which were connected through two-inch pipe leads to 80 one-inch rubber hoses. The hoses dropped into the fermentation tank and were connected to 80 Dravo flutter valve aerators located approximately one-foot above the tank bottom. These aerators were spaced in such a manner that one aerator supplied air to approximately a four ft^2 bottom area and up through a depth of six to eight feet. The dilution rate was controlled by adjusting either the influent waste feed flow rate or (as was most frequently the case) adjusting the tank volume by raising or lowering the pilot effluent flexible conduit - see Figure 2.

Various procedures were used to harvest the fungal solids. The most successful was to continuously exit the fermentor effluent containing the fungal flocs into a 2000 gallon cone clarifier. Proper positioning of the fermentor effluent line in the clarifier allowed discharge and rapid settling of the fungal flocs to the clarifier bottom while lighter fungal fragments and undigested waste particulates floated out at the clarifier top. Proper positioning of the fermentor discharge (X) and the clarifier baffles (B) for maximum floc collection efficiency are shown in Figure 2. The total residence time in the clarifier was approximately 1 hour and a solids (fungal) concentration from the clarifier underflow was 3 to 4%. The

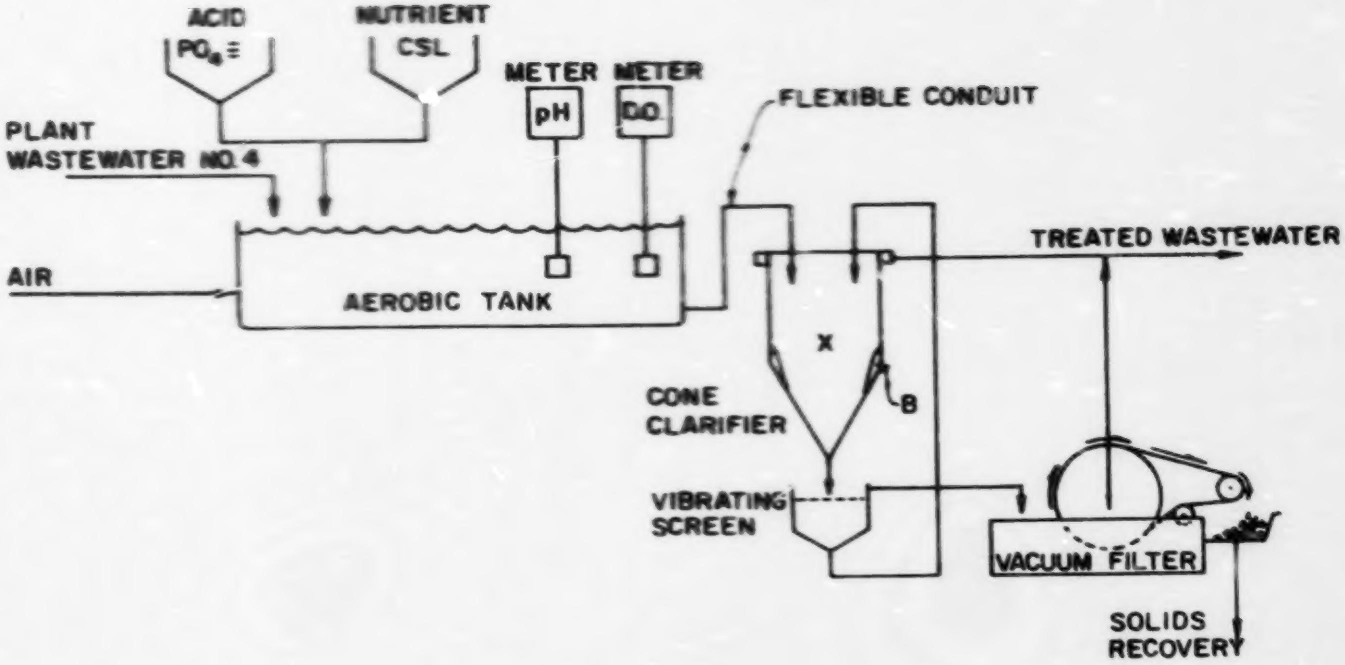

ACID
$PO_4^{\equiv}$
NUTRIENT
CSL
METER
pH
METER
DO
PLANT
WASTEWATER NO. 4
FLEXIBLE CONDUIT
AIR
AEROBIC TANK
TREATED WASTEWATER
X
B
CONE
CLARIFIER
VIBRATING
SCREEN
VACUUM FILTER
SOLIDS
RECOVERY

Figure 2. FLOW DIAGRAM OF FUNGAL PILOT PROCESS.

vibratory screen, shown in Figure 2, was found to be an unnecessary harvesting step in subsequent studies and the clarifier underflow was discharged directly onto the Amatec continuous vacuum belt filter. A fungal cake of 3/8 to 1/2 inch thickness and 20 to 22% solids was continuously discharged from the vacuum screen as shown in Figure 3.

Full-Scale Process

A full-scale, 3 x 10^6gal. fungal treatment plant was constructed following the pilot studies at Penick and Ford. The fermentation facility consists of two 1.5x10^6gal. circular, 40 ft. high by 80 ft. diameter, coal tar resin lined steel plate tanks. Air is supplied by Worthington positive pressure, two stage, intermittent cooling blowers. The air is blown through header pipes into the bottom of each tank. From there, the air is routed through the tank bottom pipe distribution system before escaping up through 16 six foot verticle Kenick spiral aerators per tank. Since the two fermentation tanks are run in "series", the first (north) tank is always full and the waste water flows from a pipe near the top of the first tank into the second (south) tank. By varying the volume of the second (south) tank, one can vary the total residence time of the system.

Two alterations were introduced into the fungal treatment process following construction and operation of the full-scale plant. One change was to allow the total treated plant effluent to discharge into a lime neutralizing tank before entering the cone clarifiers. This alteration of the pH from 4.5 to 7.0 in the harvest system allowed the fungal solids to settle faster in the cone clarifier than experienced in the pilot system and provided a pH 7.0 effluent discharge from the clarifier overflow to the city waste treatment plant. The other alteration introduced into the system was to replace the vacuum belt filter following the clarifier step with a DeLaval Basket Centrifuge. This fungal harvesting change resulted in a more economical, energy efficient, and higher dewatered solids product. Thus, the 20 to 22% dewatered solids from the vacuum filter was raised to 32% fungal solids by this equipment change.

Drying of the 32% fungal solids was studied under a variety of conditions and will be briefly described under RESULTS.

Start-up of all continuous fermentations in the laboratory, pilot, and full scale processes was carried out according to the inoculation-dilution technique described to the author by the late Dr. H. Orin Halvorson. In accordance with this procedure, 1/3 the total fermentor volume was filled with raw waste. The remaining 2/3 volume was filled with water. Inoculation of the fermentor consisted of a 15 to 20% actively growing vegetative fungal mycelium added with respect to the waste substrate volume not to the total fermentor volume. Employing start-up procedure, continuous fermentations were initiated at zero time. The inoculation-dilution relationship used in these studies is shown in Figure 4 where the "theoretical" build-up of the waste substrate, assuming perfect and instantaneous mixing and providing no digestion of the waste substrate occurs, is determined by the integrated formula shown in Figure 4. The "actual" waste substrate (COD) reduction

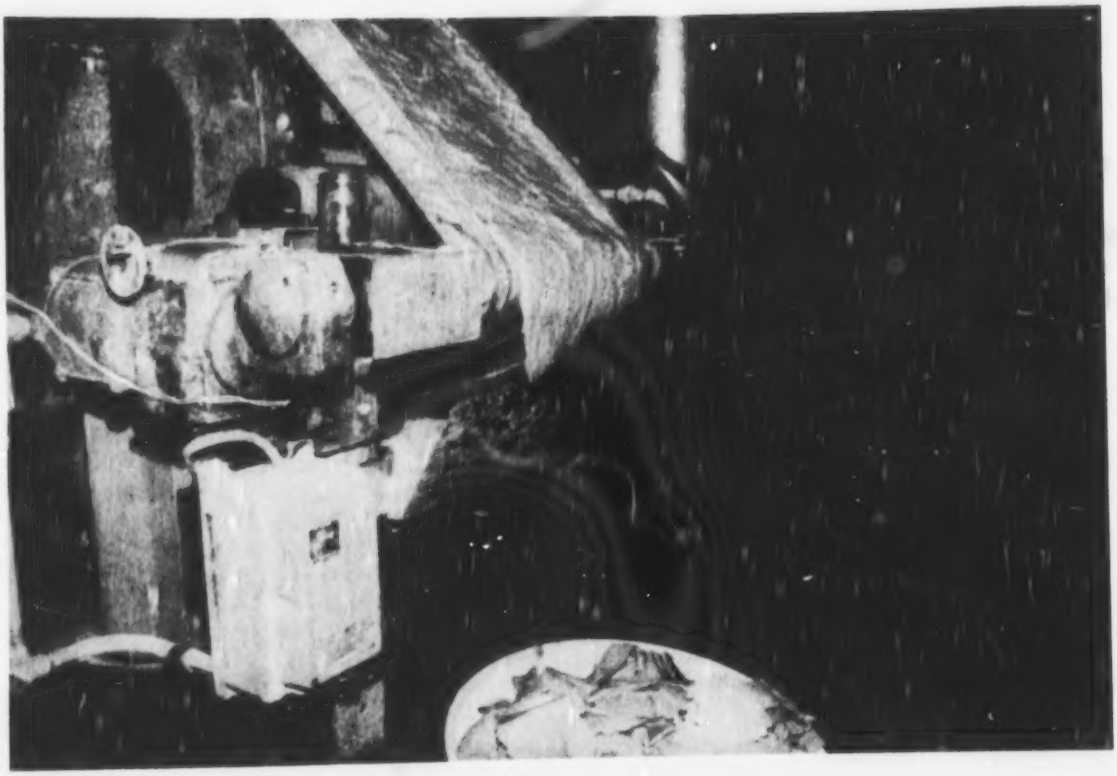
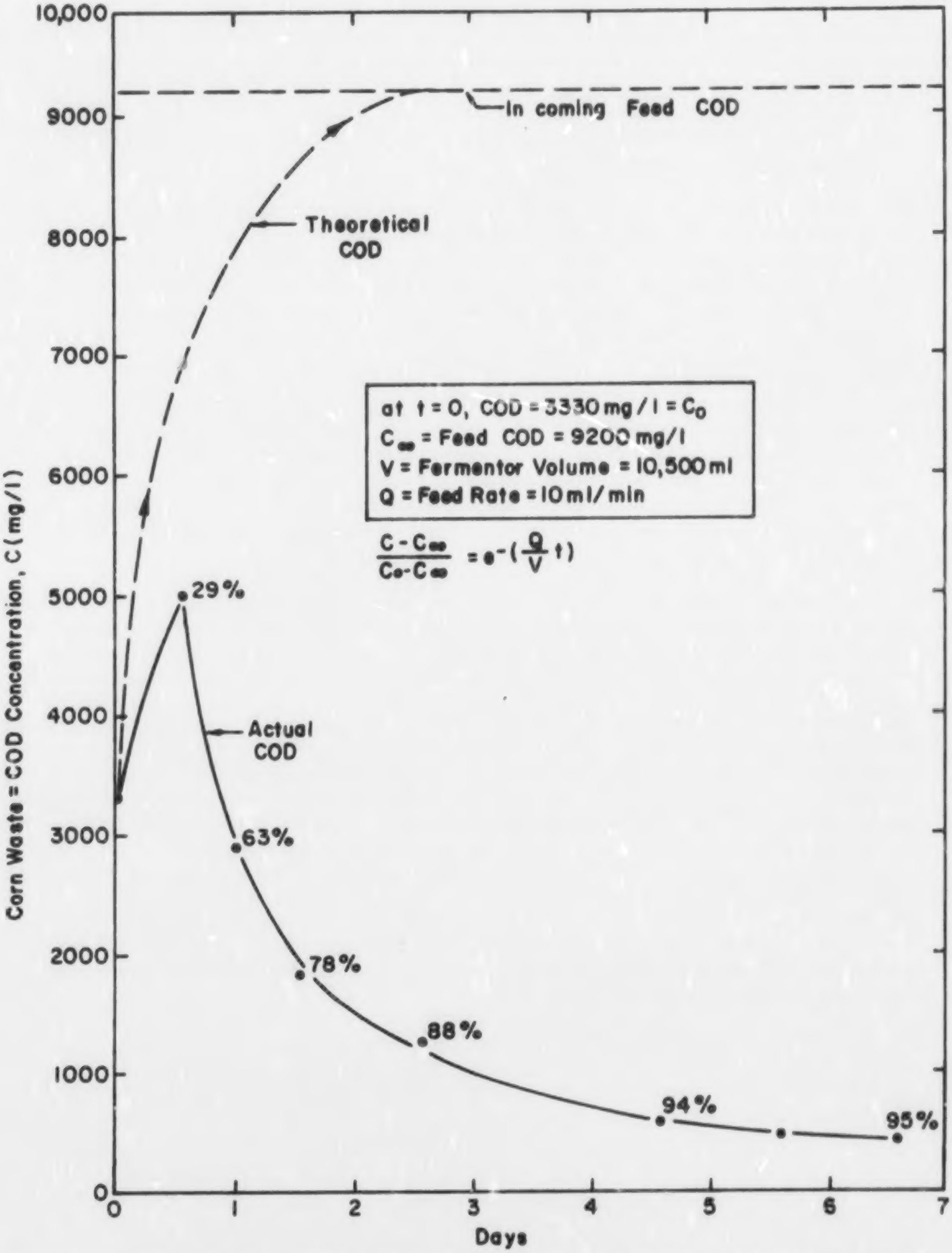


Figure 3. Continuous Belt Vacuum Filter
Showing Discharge of Fungal Cake.



$$\frac{C - C_\infty}{C_0 - C_\infty} = e^{-\left(\frac{Q}{V} t\right)}$$

Figure 4. START-UP OF CONTINUOUS FERMENTATION OF CORN WET-MILLING WASTE IN A LABORATORY FERMENTER BY GLIOCLADIUM DELIQUESCENS

shown in Figure 4 represents the effect of fungal growth and metabolism on degradation of the corn wastes and is indicated in terms of percent reduction of the "actual" COD. Although only the first seven days data are plotted in Figure 4, the continuous system operated for 14 days before termination and showed a percent waste reduction of 90 to 95 with both *T. viride* and *G. deliquescens*.

Analytical procedures used for determination of the effectiveness of fungal fermentation of the waste substrates were chiefly those described in Methods for Chemical Analysis of Water and Wastes (13). Influent and Effluent "grab" samples were taken at 6 hr. intervals. 24 hr. composite samples made-up from the 6-hr. "grab" samples were also analyzed. All samples were filtered through Whatman #4 filter paper under slight negative pressure and the filtrates and retentates dried on the tared filters and in tared dishes overnight at 95°C. Weights from the tared filters were recorded as fungal mass and from the tarred dishes as total solids for all effluent samples. Influent samples were not filtered prior to drying except in instances where suspended solids were measured. Retentate samples were also heated at 650°C for 2 hrs. for determination of volatile solids and ash. In the pilot and full scale processes samples were never less than 1 gallon each. During start-up and periods of operational breakdown samples were taken more frequently than at the six hour intervals.

A routine procedure used in all these studies for evaluation of process well being or malfunction was that of phase microscopy. Microscopic changes in fungal morphology reflected gross changes in the fermentation process and deviation from the steady-state. The method was simple, reliable, rapid, and required minimal operator training. The method was enthusiastically endorsed by the chemical engineers! Optimal fermentation conditions resulted in a phase microscopic picture of fungal morphology that revealed a homogeneous cytoplasm, long tapering mycelial branches devoid of septa, and somewhat swollen hyphae which occasionally contained an early developing arthospore. Lysing and sporulating mycelium, on the other hand, indicated nutrient starvation or a too low dilution rate. The microscopic technique could also be used to verify a well-mixed fermentation system, or conversely, pick out "dead" areas (poor nutrient mixing, oxygen starvation, etc.) by employing a grid or patterned microscopic slide sampling examination of the fermentation tank. Other information obtained from this technique included estimates of the level of contaminating microorganisms and undigested waste substrate particulates.

The techniques and methodologies used in these studies to evaluate the fungal drying, and animal feeding quality of the fungal protein will be included with the experimental procedures and results in the following sections.

RESULTS

Development of Continuous Fungal Growth and Waste Substrate Utilization

a. Laboratory Studies

Laboratory and pilot experiments were conducted under batch culture conditions in the fermentation apparatus described under METHODS and the data were used to determine fungal growth rates and substrate (waste) utilization optimums with *T. viride* and *G. deliquescens*. Attempts were made to define the C:N:P (carbon to nitrogen to phosphate) ratio of the influent substrate medium in the hope that such a ratio would indicate the optimal rate of waste substrate utilization and the highest fungal mass yield. Such studies conducted in batch culture pointed up the need for additional nitrogen and phosphate above what was supplied by the raw waste substrate. Thus, it was determined that a carbon (carbohydrate + organic acid) to nitrogen (protein and ammonia nitrogen from corn steep, urea, and ammonium sulfate) to phosphate (derived from the waste ash + added sodium dihydrogen phosphate) ratio was approximately 50:10:1. This ratio is shown in the influent waste column of Table 3 which also contains the data from a continuous culture laboratory experiment where steady state balanced growth was maintained.

Initially, experiments were undertaken to generalize the given relations of fungal growth mathematically in batch culture. Maximum growth rates (μ max) and COD reductions were measured in several media to evaluate fungal growth and protein formation. Fungal growth at 26°C in an excellent synthetic salts-urea-dextrose medium (Mandel's medium) was compared to a corn wet-milling waste medium both of which contained excess nitrogen and phosphate. One external physical condition, pH, was studied in the two media. The results are shown in Table 1.

TABLE 1. EFFECT OF PH AND MEDIA ON THE GROWTH RATE OF FUNGI

Fungus	pH	Mandel's Salts + Urea + Dextrose		*Corn-Wet-Milling + 1% Corn Steep	
		td 1+RS hrs.	μ hr^{-1}	td 1+RS hrs.	μ hr^{-1}
Trichoderma viride	3.5	4.2	0.164	11.1	0.062
	4.5	3.6	0.193	8.6	0.080
	6.0	5.1	0.137	10.3	0.067
Gliocladium deliquescens	3.5	8.4	0.083	9.6	0.072
	4.5	8.1	0.086	10.0	0.069
	6.0	9.1	0.076	10.4	0.066

*Mixed corn starch, 66%; corn syrup, 33%; and heavy corn steep liquor (51% solids), 1%. Sodium dihydrogen phosphate added, 100mg/1.
td = time to double fungal mass
μ = specific growth rate, slope of exponential growth rate line.
Cultures grown at 26°C with excess oxygen.

The importance of the growth rate as a criterion of the state of the culture as a whole, is well understood and is expressed here in the mathematical relations derived by Monod (14). The data used here were derived algebraically by analysis of the fungal growth of the cultures in batch process during the period of logarithmic growth. Growth results in the two media at three pH levels are shown in Tabel 1. The fungal mass average doubling times (td) were determined by calculation from the straight line part of the growth curve in these media. The data were obtained from periodic samples of the culture in which dry weights of the fungal mass (g/1), were plotted vs. time (hrs.). The specific growth rates (μ) were calculated and also shown in Table 1. μ is the slope of the exponential growth and a meaningful indication of the change in the culture. Since any restriction in the internal (carbon, nitrogen, phosphorous) or external (pH, temperature, oxygen) environment is reflected in the specific growth rate of the fungus, operational deficiencies in a pilot plant situation can be detected quickly. In spite of the chemical differences in the two media and the pH range, G. deliquescens showed less variability in doubling times and specific growth rates than did T. viride. In all cases the optimal pH appeared to be approximately 4.5 and Mandel's medium superior to the corn waste. Since there were no restrictions imposed on the cultures in these growth media the specific growth rates should be considered maximum (μ max).

Use of a limiting nutrient, in our case the phosphate concentration, allows use of Monod (14) equations where growth increase with respect to time is proportional to the fungal mass present at that time, and we can calculate the specific growth rate (μ) of the fungal mass. The purpose of the kinetic study in the batch culture system was to find both the maximum fungal mass growth rate and the maximum waste substrate utilization in order to evaluate the residence time and dilution rate for further design of a continuous waste treatment process. Using the data plotted in Figure 5, the specific rates within the linear or log phase of growth are defined as:

A) Specific growth rate of fungus is μ

$$\text{and } \mu = \frac{1}{M^*}\frac{dM}{dt} = \frac{d\ln M}{dt} \text{ at } T^*$$

where t = time
T* = 26 hour point
M = fungal mass
M* = fungal mass at T* = 1.0g/l
S = substrate as COD, BOD_5, or TOC

B) Specific rate of substrate utilization is μ'

$$\text{and } \mu' = \frac{1}{M^*}\frac{-dS}{dt} = \frac{d\ln S}{dt} \text{ at } T^*$$

$$\text{then } \mu' = \frac{1}{M^*} - \frac{\ln S_2 - \ln S_1}{t_2 - t_1}$$

and assuming a first order reaction behavior

$$td \text{ or } td' = \frac{\ln 2}{\mu \text{ or } \mu'} = \frac{0.693}{\mu \text{ or } \mu'} = \text{hours}$$

where td = doubling time of fungal mass
td'= ½ life time of substrate

The G. deliquescens experiment shown in Figure 5 demonstrated termination o growth and substrate utilization by the concentration of the growth limiting nutrient, phosphate. In this experiment, following an initial lag period, the substrate began to disappear and the rate of substrate utilization and fungal synthesis were calculated between the 20 and 30 hour time periods. During this time period, microscopic examination showed the fungal mycelium to have numerous, homogeneous growing hyphal tips and no evidence of sporeulation. Calculations of the specific growth rate (μ) and substrate ½ life are shown below:

Fungal Mass:

Where T* = 26 hr. and M* = 1.0g/l

$$\mu = \frac{d\ln M}{dt} = \frac{7.30 - 7.91}{10} = \frac{0.61}{10} = 0.061 \text{ hrs}^{-1}$$

$$td = \frac{0.693}{0.061} = 11.4 \text{ hours}$$

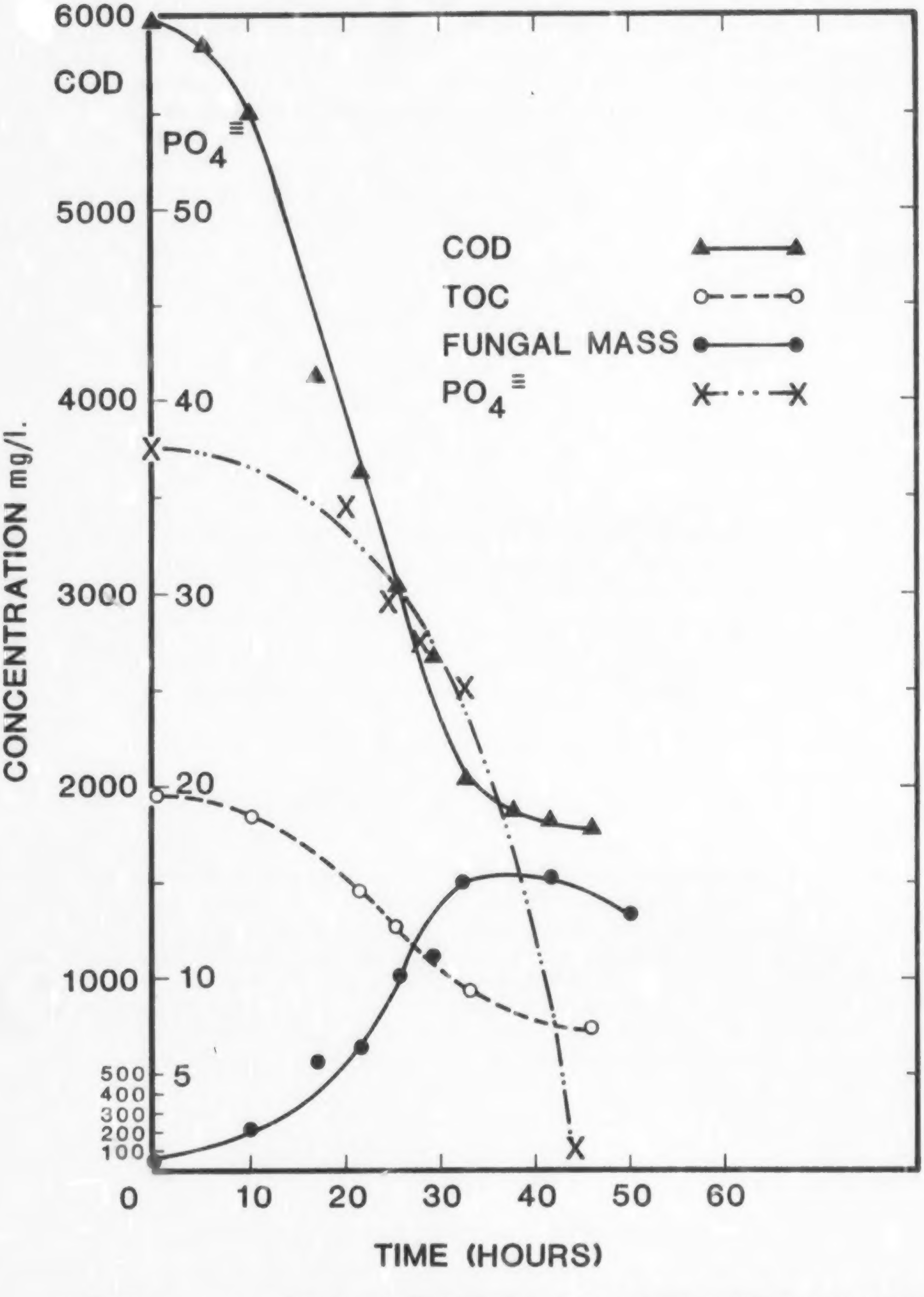


FIGURE 5. BATCH DIGESTION OF CORN WET-MILLING WASTE BY GLIOCLADIUM DELIQUESCENS.

For Substrate Utilization:

$$\underline{\text{COD}} \quad \mu' = \frac{1}{M^*}\left(-\frac{d\ln S}{dt}\right) = \frac{1}{1}\left(\frac{4.7 - 3.0}{10}\right) = 0.17 \text{ hrs}^{-1}$$

$$td = \frac{0.693}{0.17} = 4.07 \text{ hours}$$

$$\underline{\text{TOC}} \quad \mu' = \frac{1}{M^*}\left(-\frac{d\ln s}{dt}\right) = \frac{1}{1}\left(\frac{0.55}{10}\right) = 0.055 \text{ hrs}^{-1}$$

$$td' = \frac{0.693}{0.055} = 12.6 \text{ hours}$$

Calculation of the waste substrate half-life can be misleading depending on the carbon parameter one chooses for evaluation. As shown in Figure 5 and Table 2, the initial COD value is 3 times the TOC and the rate of utilization of COD to TOC is 3 times faster. It would appear, therefore, that G. deliquescens incorporates carbon into cell mass with a conversion efficiency of approximately 33% if the COD is used and 100% if the TOC is used. 100% conversion is obviously incorrect since it would not allow for carbon oxidation for energy purposes required to synthesize cell mass. On the basis of doubling times (td and td'), the COD and carbon measurements would indicate that 37% of the carbon in converted to cell mass and 63% to energy and heat. CO_2 evolution measurements during the course of this experiment would have resolved the dichotomy. It would appear, from other data not shown here, that the COD test better reflects the carbon fate than does TOC. On the basis of COD, the data in Figure 5 and data from other experiments summarized in Table 2 indicate that carbon is incorporated into cell mass more efficiently by T. viride (61%) than by G. deliquescens (36%).

TABLE 2. KINETICS OF GROWTH AND SUBSTRATE UTILIZATION

Fungal Strain	Growth: Specific Rate μ hr^{-1}	Growth: Doubling Time td hours	Substrate Utilization: Carbon COD TOC	Substrate Utilization: Specific Rate μ' hr^{-1}	Substrate Utilization: ½ Life of Substrate td' hours
T. viride	0.067	10.4	COD	0.109	6.35
G. deliquescens	0.061	11.4	COD	0.170	4.07
			TOC	0.055	12.60

It will be necessary for the investigator to preestablish which parameter to use for carbon balance studies and to include a CO_2 measurement before the true ½ life of substrate utilization can be determined. This would be critical to establishing optimal continuous fermentation and overall process economics in the waste systems.

Continuous fermentation studies were initiated in the same apparatus used for the previously described batch studies. The dilution rates of the continuous systems were the same as the fungal growth rates found earlier in the batch studies. Since ($dM/dt = \mu M$) for rate of the fungal mass growth and since the rate of loss of fungal mass through continuous overflow also equals (dM/dt) and can be stated, $dM/dt = f/v = DM$, where the flow rate (f) is measured in culture volumes (V) per hour, then the expression (f/VM) is called the dilution rate (D), thus:

$$\mu M = DM \text{ and } \mu = D$$

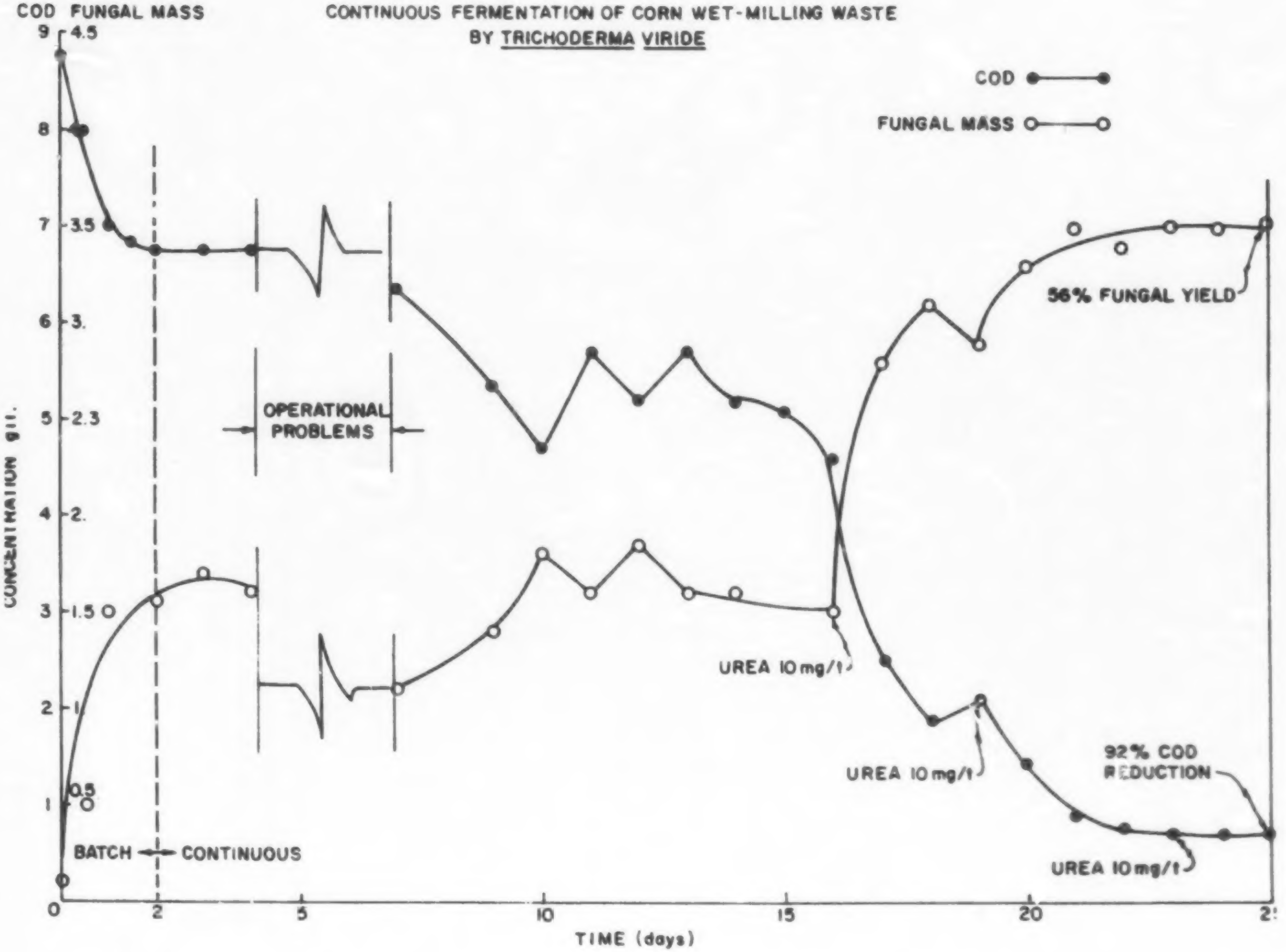
which states that the fungal growth rate equals the fermentor dilution rate in a stabilized continuous system. The concentration of phosphate was the limiting substrate nutrient to maintain the steady state; the waste medium, pH 4.5, excess oxygen, and temperature were all set at the same level as used in the batch studies.

The continuous fermentation was set-up as a batch system for the first 48 hours with T. viride and fungal mass adjustment was believed to have occurred, the system was switched to continuous. The residence time was set at 10.4 hours or a dilution rate of 0.067 hr^{-1} in accordance with the batch studies (Table 2). As indicated in Figure 6, operational difficulties plagued the continuous system from day 4 through 7. Resolution of these pH, feed line, air pump, etc. problems, resulted in system adjusted to a steady state at day 10 through 16. Nitrogen determinations made during the day 10 to 16 interval showed the system was being controlled by a limiting concentration of nitrogen - phosphate was decreased but not limiting. Thus, nitrogen in the form of urea was added at days 16, 19, and 23. Apparently both nitrogen additions at days 16 and 19 relieved the nitrogen restriction and allowed the controlling influence of limiting phosphate concentration to maintain the steady state which continued for another two weeks before termination. During the two week period following fungal adjustment to the second urea addition, a number of measurements showed 90 to 92% removal of the influent COD and fungal mass yield of 56%. These results would indicate that 36% of the carbon was evolved as CO_2.

A similar continuous experiment to the one with T. viride was conducted with G. deliquescens where all conditions established to be optimal in batch studies were employed in the continuous fermentation. Thus, the dilution rate was set at the specific growth rate (μ) found previously to be 0.061 hr^{-1} or a residence time of 11.4 hours. Again a deficiency for nitrogen was corrected by adding urea and the fungal mass density was increased. Both these experiments with T. viride and G. deliquescens demonstrated that substrate nitrogen enrichment increased fungal mass density while not affecting the dilution rate or specific growth rate of the fungi. Data from the study with G. deliquescens taken from samples analyzed over a four day period following fungal adjustment after urea nitrogen addition,

Figure 6.

CONTINUOUS FERMENTATION OF CORN WET-MILLING WASTE BY *TRICHODERMA VIRIDE*



are shown in Table 3.

TABLE 3. CONTINUOUS DIGESTION OF
CORN WASTE BY GLIOCLADIUM DELIQUESCENS

Test Condition	Influent Waste mg/l	Effluent mg/l	Percent Reduction %
Total Solids	9640	3520	63
Total Volatiles	6010	520	92
Total Ash	3630	3000	18
COD	6200	545	91
BOD_5	5600	128	98
Carbohydrate	4436	310	93
Organic Acid	580	50	92
Protein -N	1030	42	96
Ammonia -N	88	2.7	97
*Phosphate	17	1.0	91
Fungal Mass	68	3500	-

* This is only phosphate added to the raw waste medium, total phosphate is not shown.

The conversion efficiency of carbon to fungal mass can be calculated from a number of parameters shown in Table 3. Again, with this experiment as was observed earlier in the T. viride experiment, much depends on which carbon parameter one chooses as to what the true values are for substrate utilization or carbon to fungal mass conversion efficiency. Subtracting the residual (C_r) carbon in the overflow effluent from the original influent carbon (C) and dividing the fungal mass by the subtracted value shows that conversion efficiencies for volatile solids, COD, and BOD_5 are all 62 to 64%. While that from the combined carbohydrate + organic acids is 75%! Since three of the four parameters are in close agreement, one is persuaded to accept any one of the three. Also, because all three include all the organic constituents of the medium additional strength is given to these parameters. On the same bases we believe the carbohydrate + organic acid parameter might be excluded. A definitive decision cannot be made, however, until more experiments are carried out and particularly experiments where total CO_2 evolution is also measured.

b. Pilot Plant Studies

Corn wastes generated at the Penick and Ford corn wet-milling plant were the same as those used in the laboratory studies. Whereas the concentration of corn starch, gluten, and syrup wastes could be carefully controlled in the laboratory, it was much more difficult to do this in the pilot work due to unforseen operational changes in the company processes. The operation of the 50,000 gallon pilot facility was initiated by the inoculation-dilution procedure described earlier and continued for 5 months. Results of the first six and one-half weeks are shown in Figure 7. COD (mg/l) is plotted vs. time in weeks and also the fungal mass (mg/l) is shown. Gaps in the influent feed indicate the hours during which the system was switched from continuous to batch operation during weekend plant shut-downs. The dilution rate was 0.043 hr^{-1} corresponding to a residence time of 16.0 hours. Although this rate was somewhat slower than that achieved in the laboratory studies, it was probably a result of fluctuating nitrogen and phosphate concentrations. Either nitrogen or phosphate could control the continuous fermentation as shown in the laboratory studies in Figure 6 by their limiting concentration effect. Since the raw waste influent concentration was undergoing radical, almost daily change, it would appear that there were very low nitrogen and phosphate levels at times when the influent COD concentration became extremely high - for example, at the 3.0 and 5 to 6 week periods. A closer control of the nitrogen and phosphate concentrations would undoubtedly have improved the yield and allowed for an increased dilution rate.

One particularly interesting feature of this treatment process shown in Figure 7 was the manner in which raw waste influent concentration extremes were reduced to a rather low, constant effluent level. The reason for this is obviously the rapid response of an increased fungl mass when the substrate level increased. The picture in Figure 7 is one of fungal mass density adjustment to variable substrate concentrations at a constant dilution rate.

Although the fungal mass yield based on conversion efficiency of the substrate was never near that obtained in the laboratory, the yield was quite variable and ranged between 25 and 50%. On several occasions when the nitrogen level was raised either by adding more corn steep or urea, an immediate improvement in fungal yield was observed. This result was similar to the seen in Figure 6 for the laboratory study.

Often the waste substrate concentration increase was not balanced with regard to starch and the syrup dextrose. When the imbalance was due to high dextrose concentration, excessive foaming occurred. Low fungal yields and an increased fungal growth rate resulted in rapid depletion of the limiting phosphate. Such an occurrence (recognized early by an increasing foam build-up) could be controlled by increasing the dilution rate from 0.043 to 0.067 hr^{-1}. When the foam subsided, the dilution rate was returned to the lower value again.

Later experimental work with the pilot system demorstrated that where a carbon to nitrogen to phosphate ratio of 50:10:1 could be maintained in the face of changing carbon (raw waste influent) concentrations, a reliable steady state condition prevailed.

Drying the 22% fungal solids from the vacuum filter or the 32% solids from the

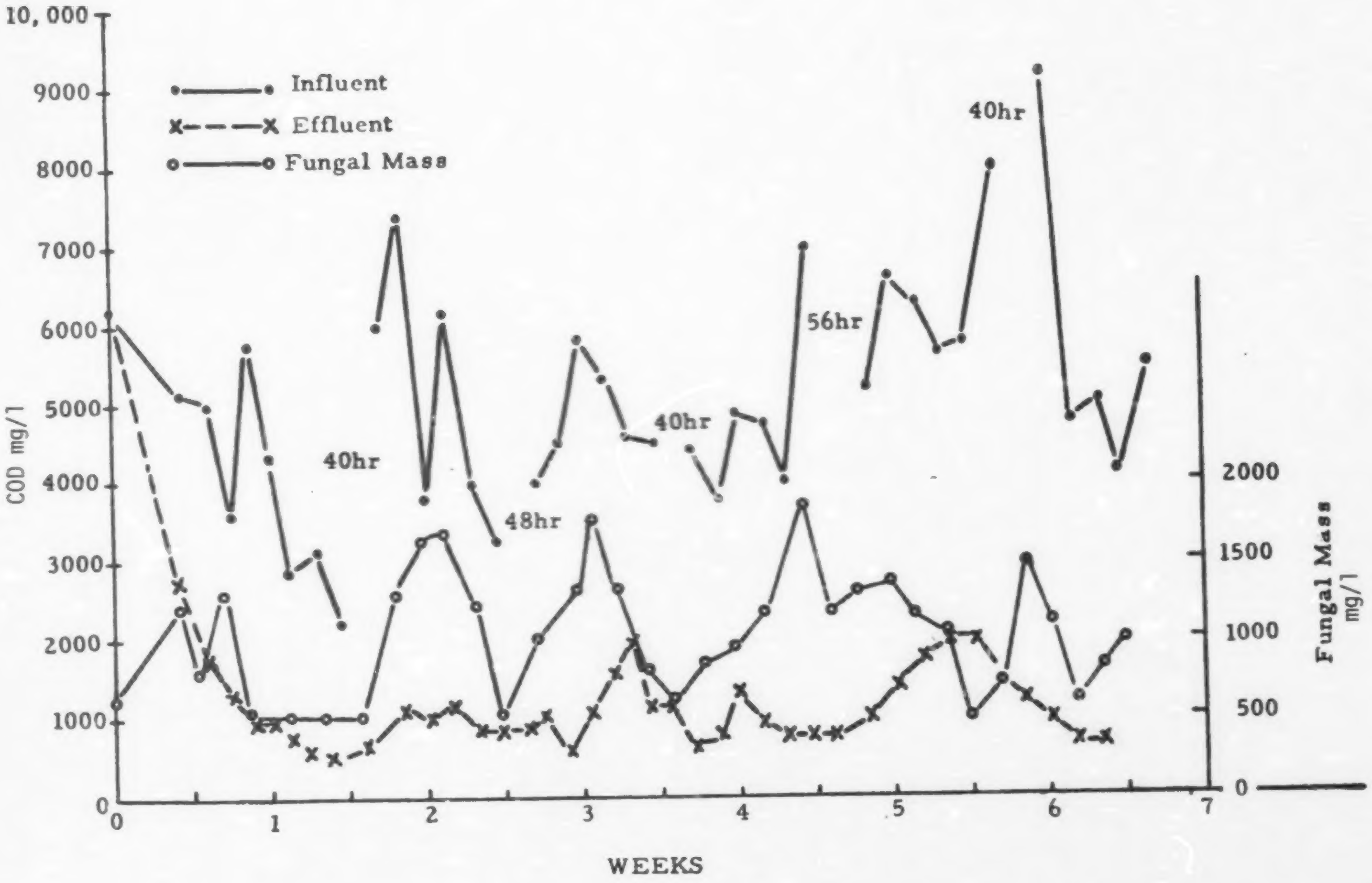


Figure 7. COD Reduction of Corn Wet-Milling Waste by *Gliocladium deliquescens*

centrifuge was carried out by several procedures. No washing of the fungal solids was done prior to drying. The conditions used for drying the fungal mycelium and the protein content after each drying procedure are shown in The Flow Diagram, Figure 8. The protein content of each dried sample was determined from amino acid analysis. Although not carried out in these studies, we believe premixing the vacuum filter or centrifuged solids cake with other animal feed ingredients prior to drying would improve the protein content of the biomass through protection. Under these conditions it would appear that almost any drying procedure where the temperature was held at 70°C would not unduly compromise the protein. The higher drying temperatures appeared to reduce the level of the essential amino acids; lysine, tryptophane, and methionine more than the others. Since methionine is already deficient in this protein for nutritional quality of most animals, the drying procedure used becomes a step of critical significance.

The amino acid levels of the *T. viride* and G. *deliquescens* protein has been reported before (5, 10, 11) and both fungi demonstrated levels of the essential amino acids, an leucine-iso-leucine ratio, low proline, and over all amino acid balance comparable to soy protein. In addition to an excellent amino acid balance, the fungi used in these studies had excellent vitamin levels as shown in Table 4. The fungal vitamin level was obtained from lyophilized pilot plant material. Vitamin analyses of some other food materials are also shown for comparative purposes (15, 16).

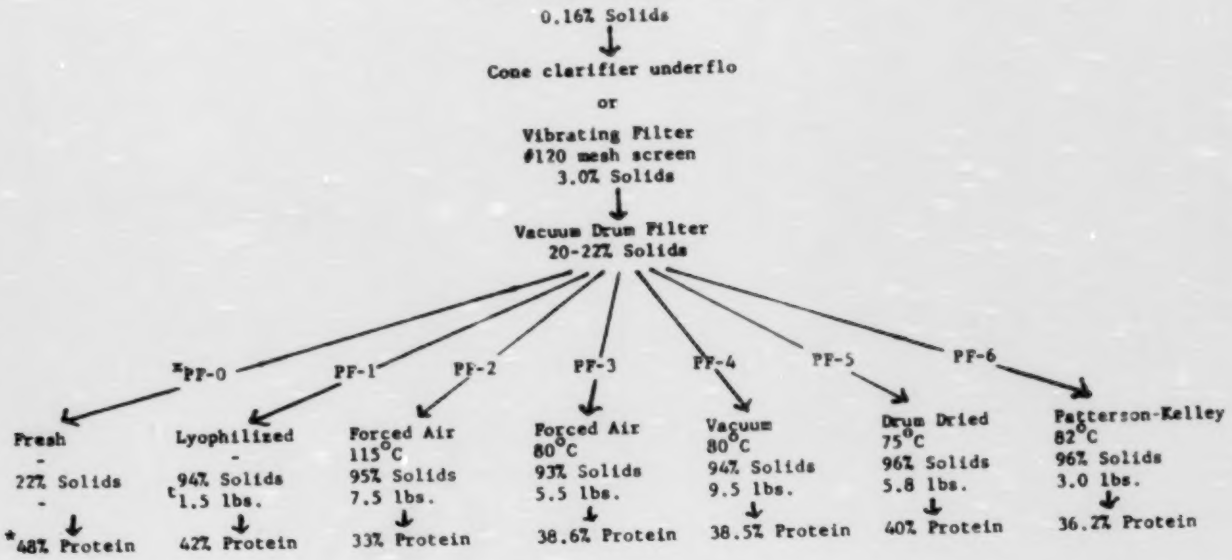
TABLE 4. FUNGAL VITAMIN LEVELS
COMPARED TO OTHER FOOD MATERIALS
(VALUES EXPRESSED AS mg/kg. DRY WEIGHT)

Vitamin	Fungal	Beef	Beef Liver	Yeast	Milk Dry Whole	Cereal
Thiamine	15	1-3	5-10	2-20	3.4	1-7
Riboflavine	160	2	16	30-60	15	1-2
Nicotinic Acid	575	40-100	75-275	200-500	7.3	10-30
Pantothenate	167	7-21	30-60	30-200	20	5-20
Pyridoxine	38	1-4	5	40-50	1-3	3-6
Cobalimine	10	-	8	8	4	-
Biotin	4	-	-	1-5	0.3	-
Folic Acid	18	-	-	21	0.02	-
Choline	-	-	-	2000	862	2000
D-Ergosterol	20	-	-	-	-	-

It was observed by Champagnat *et*. *al*. (15) that drying a product (in his case, yeast) at low pH could lead to vitamin losses, particularly the

Figure 8.

Flow Diagram of Fungal Treatment
of Corn Wet Milling Waste
Pilot Plant Effluent Solids


0.16% Solids
Cone clarifier underflo
or
Vibrating Filter
#120 mesh screen
3.0% Solids
Vacuum Drum Filter
20-22% Solids
xPF-0
PF-1
PF-2
PF-3
PF-4
PF-5
PF-6
Fresh
-
22% Solids
-
*48% Protein
Lyophilized
-
94% Solids
t1.5 lbs.
42% Protein
Forced Air
115°C
95% Solids
7.5 lbs.
33% Protein
Forced Air
80°C
93% Solids
5.5 lbs.
38.6% Protein
Vacuum
80°C
94% Solids
9.5 lbs.
38.5% Protein
Drum Dried
75°C
96% Solids
5.8 lbs.
40% Protein
Patterson-Kelley
82°C
96% Solids
3.0 lbs.
36.2% Protein

* = All proteins based on amino acid analysis (GLC)

t = lbs. = pounds on hand in storage at D.R.I.

x = Code designations = PF-1, PF-2, PF-3, etc., designate Penick and Ford fungal material harvested and dried, 4/72 water soluble vitamins. Our material was dried at pH 4.5, therefore some of the vitamin levels shown in Tabel 4 could be minimal values. Nevertheless, the fungal vitamin levels shown here are equal or higher than those contained in the other food materials.

Animal Feeding Evaluations of the Safety and Quality of the Fungal Product

According to PAG Guidelines the physical, chemical, and animal feeding properitles of the industrial product should be essentially the same as those of the experimentally tested material. To be truly significant, the studies should be conducted on the fungal product as made on a production scale rather than on laboratory batches. Also particular attention must be directed to the composition of the fungal growth medium from the viewpoint of the possible presence of chemical components regarded as hazardous to health. In answer to these requirements and according to the studies performed and reported in this paper, the source materials which form the substrates for the growth of the nutritive fungal material are the same basic substrates which are utilized for the various food products manufactured by this company. In addition, the fungal product used in these animal feeding studies was the material harvested and dried from both the pilot and full-scale industrial treatment facilities reported herin.

Gross chemical component analyses of the fungal product are shown in Table 5. Although these analyses are not definitive to show the possibility of the presence of toxic contaminants derived from fungal metabolism or from the source substrate materials (e.g. pesticides, lubricants, binders, heat processing reactants, etc) it was assumed that the presence of any hazardous feed materials in the fungal product would be detected in the course of sensitive animal feeding trials.

TABLE 5. GROSS CHEMICAL COMPONENTS
OF PILOT PLANT HARVESTED FUNGAL PRODUCT

Chemical Component	Percent of Dry Weight
Protein	45
Carbohydrate	30
Nucleic Acid	5
Lipids	4
Ash	6
Moisture	10
Vitamins	0.1

The data shown in Tables 4 and 5 together with that on amino acids (5, 10,

11) were used to formulate the animal diets for the feeding trials described hereafter.

Animal feeding trials were conducted with weanling rates, chicks, mice, nursing piglets, and gilts. Only the details of feeding trials in rats and chicks will be reported here.

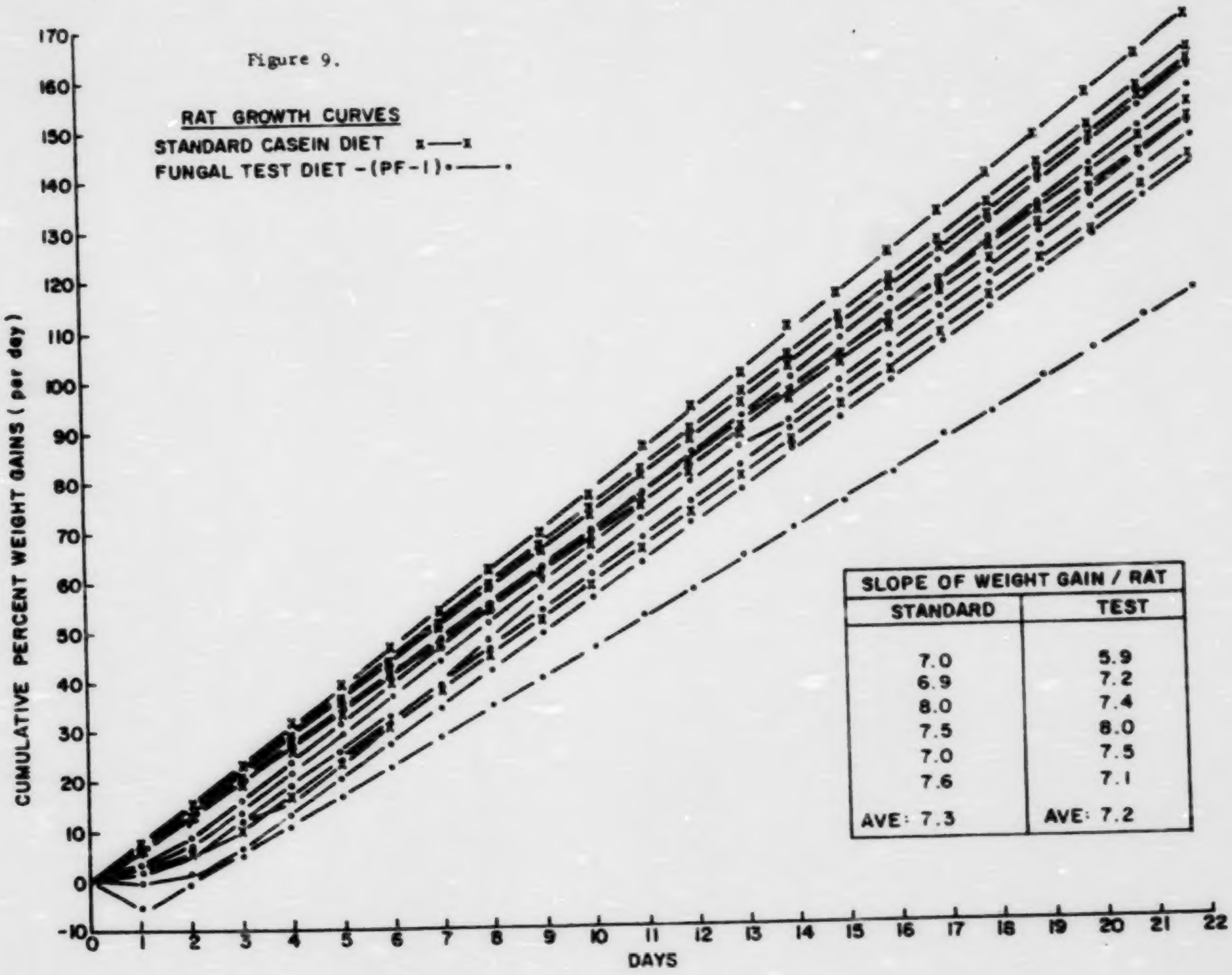
a. Weanling Rat Feeding Trials

Three types of feeding trials were conducted in weanling rats employing fungal biomass as the protein supplement in the animal diets. These were:
1) Growth response over a 3 week period
2) Protein Efficiency Ratio (PER)
3) Nitrogen Balance tests to determine the biological value (BV), true protein digestibility (TPD), and net protein utilization (NPU).

Three diets were formulated for these trials: one, a 3% egg protein adjustment diet; two, a standard control casein diet; and three, a test fungal diet in which the casein was replaced by fungal protein. After a two week adjustment period the weanling rats were placed on the standard and test diets. During the experimental three week feeding period in which feed and water were fed *ad libitum*, animal weights, feed intakes, urine, and fecal samples were recorded and collected for each rat each day. The protein levels were set at 23% of the diet and rats were fed fungal protein from each drying condition utilized in Figure 8. Growth rates of rats fed the lyophilized fungal and casein control diets are shown in Figure 9. The curves represent cumulative percent weight gains for the rats fed these diets. The slope of weight gain was determined for each rat and the average of the slopes (see insert in Figure 9) for the casein and fungal protein fed animals showed no significant difference. Growth of rats fed the other dried fungal diets were somewhat less favorable ranging from 74 to 94 percent of the growth demonstrated in Figure 9.

Protein efficiency ratio (PER) evaluations do not distinguish between utilization of protein for maintenance and that needed for growth, however it is probably the most commonly used procedure. PER involves the average net gain in body weight per unit weight of protein consumed. The PER's of each of the dried fungal materials were compared to the casein control. The data shown in Table 6 demonstrates the loss in protein efficiency due to the particular drying condition imposed on the fungal biomass prior to diet formulation and feeding.

Figure 9.



SLOPE OF WEIGHT GAIN / RAT	
STANDARD	TEST
7.0	5.9
6.9	7.2
8.0	7.4
7.5	8.0
7.0	7.5
7.6	7.1
AVE: 7.3	AVE: 7.2

TABLE 6. PROTEIN EFFICIENCY RATIOS
(WEANLING RATS)

Animal Group No.	No. of Rats/ Test	Dried Fungal Material Diet	Ave. Wt. Gain Gms.	*Ave. Protein Intake Gms.	PER
1	6	Casein Std.	142.0	60.0	2.37
2	6	PF-1 (lyo)	141.3	62.2	2.28
3	6	PF-2 (Air-115C)	130.0	77.1	1.69
4	6	PF-3 (" -80C)	141.0	69.0	2.04
5	6	PF-4 (Vac.80C)	125.4	72.0	1.74
6	6	PF-5 (Drum Dry)	140.0	65.0	2.15
7	6	PF-6 (Pat.Kelley)	120.5	70.6	1.71
8	6	PF-1 (lyo) (no vitamin supplement in Group 8)	139.9	62.2	2.25

*Total feed consumed times x 23% protein

Group 8 rats fed unheated (lyophilized fungus) without the vitamin supplement used in all the other groups, showed a PER which demonstrated that the fungal material could supply the vitamin requirement as well as the protein needed for rat growth.

Nitrogen balance procedures, originally used for studies in man (17), have recently been widely used for rat evaluations of novel protein sources (18, 19). By these procedures, one can differentiate between the degree of digestibility of the nitrogen source and the proportion of nitrogen retained for storage or anabolism. In other words, nitrogen balance techniques permit differentiation between the proportion of dietary nitrogen absorbed, whcih is a function of the susceptibility of the protein source to the action of the gastrointestional proteolytic enzymes; and the proportion retained in the body, which is a function not only of the essential amino acid composition and content, but of the total protein content and the caloric density of the diet.

Digestibility and net protein utilization (NPU) were based on nitrogen analyses of the animal feeds, urine, and fecal samples collected separately each day during the rat feeding experiments described above. These are apparent digestibility and NPU values, since no endogenous or metabolic nitrogen was measured. Thus, on the basis of diets containing 23% protein, the apparent digestibility for rats fed the standard casein and the fungal test diets were 97% and 94% respectively. These values were determined from the standard nutritional formula of: $\left(\frac{IN - FN}{IN} \times 100\right)$ where (IN) is the intake nitrogen from the feed and (FN) is the fecal nitrogen. NPU values were determined according to the nutritional formula: $\left(\frac{IN - (FN + UN)}{IN} \times 100\right)$

showed a net protein utilization of 75% for standard casein diet and 50% for the fungal (PF-1) diet. The 50% NPU of the fungal diet was undoubtedly a low value since no corrections were made for endogenous, metabolic or that approximately 20% of the nitrogen of the fungal mycelium was non-protein nitrogen.

Because of the importance of nitrogen balance data on protein feed quality and because 50% NPU was at variance with the growth response curves, PER, and digestibility data for the fungal protein; a second nitrogen (NPU) study was undertaken in which endogenous and metabolic nitrogen were also measured. Digestibility (TPD) is measured in terms of the ratio of the absorbed nitrogen to the total nitrogen (i.e., the difference between the ingested and intestinally excreted nitrogen, the latter corrected for "metabolic- N"). Nitrogen retention (BV) is calculated from the ratio of the retained nitrogen to the absorbed nitrogen (i.e., the difference between absorbed N and that eliminated in the urine, corrected for so-called "endogenous-N"). The procedures used in these measurements are according to the techniques of Njaa (20).

The results of these nitrogen reevaluation studies are shown in Table 7.

TABLE 7. NITROGEN BALANCE DATA

Animal Group No.	Diet	No.of Rats Fed	Ave. Wt. gm.	Ave. N-in (IN)	Ave. Urine (UN)	Ave. Fecal (FN)	Endog. N (EN)	Metab. N (MN)	BV[1]. (%)	TPD[2]. (%)	NPU[3]. (%)
1	Casein	7	250	1.08	0.382	0.090	0.144	0.087	77	97	75
2	PF-1	8	220	1.20	0.451	0.240	0.139	0.092	74	90	67
3	PF-3	7	247	1.35	0.449	0.349	0.134	0.079	76	80	61
4	PF-5	7	240	1.28	0.507	0.363	0.148	0.083	73	86	63
5	PF-1 (no vitamin supplement	6	160	1.21	0.460	0.235	0.136	0.093	73	88	64

1. BV (biological value) = IN - (UN - EN) ÷ IN
2. TPD (true protein digestibility) = IN - (FN - MN) ÷ IN
3. NPU (net protein utilization) = Product of BV and

TPD or $\frac{IN - (FN + UN)}{IN}$ corrected for EN and MN.

The nitrogen balance data; BV, TPD, and NPU shown in Table 7 compares the four fungal feeds on these bases to the casein control and to each other. Although differences can be seen in the four dried products from the same harvest. The lyophilized material was the best although the other two were not all that much poorer. Unlike the NPU results obtained earlier where endogenous and metabolic nitrogen were not considered,these NPU values showed the fungal protein to be comparable to the casein control diet when the corrections were included.

All of the animals on the fungal diets appeared healthy, with clean fur, and bright eyes. No animals had thin coats, bloody noses, or showed any signs of baldness. Several animals fed the PF-4 fungal material to 70% of their diet had tarry black stools. Autopsies showed no difference in average organ weights between the casein and fungal fed rats. Only in the case of those rats fed the PF-2 (air dried - 115°C) and PF-4 (vacuum dried-80°C) diets, was there some evidence of fatty livers and excess internal fat. These diets, however, were not considered "preferred" diets.

b. Chick Growth Feeding

Fungal feeding experiments were conducted using one week old birds to evaluate the nutritional quality and the toxicity of the fungal biomass as a total protein replacement for casein and soybean protein in chick diets. Feed and water were proveded ad libitum. The Cornish Red - New Hampshire White cross birds were randomized, wing banded, weighed, and separated into groups of 5 chicks each. Each group had two replications Forty chicks, age one-day, were placed on a pre-experimental soybean-casein diet for one week before being grouped and placed on the fungal experimental diet for a six-week growth trial. Thus, the groups of birds were separated and Group 1 fed soybean diet, Group 2 fed the casein diet, and Groups 3 through 8 fed the various fungal (PF-1, PF-3, PF-5, etc.) diets. The protein content of all diets was 22% and DL-methionine was added to the soybean and fungal diets.

As shown in Figure 10, chicks fed the three experimental fungal diets showed no significant difference in weight gain when compared with chicks fed the two control diets during the six-week experimental period. Indeed, the total weight gain of chicks fed the fungal (PF-1) diet was greater than weight gains from the control diets. This PF-1 growth was not significant however, at the 0.05 probability level. Since there was no significant difference in feed consumption or conversion between the experimental and control groups, it was concluded that all the experimental fungal diets were satisfactory for chick growth. Mortality did not occur in either the control or experimental chick groups.

Feed efficiencies, determined by dividing the weight gained by the feed consumed, ranged from 45% for the control to 50% for the test fungal material. Feed conversion, or the inverse of feed efficiency and often used in place of feed efficiency, showed the fungal diets to have a slightly higher value than the controls - but the difference was not significant $(P < 0.05)$.

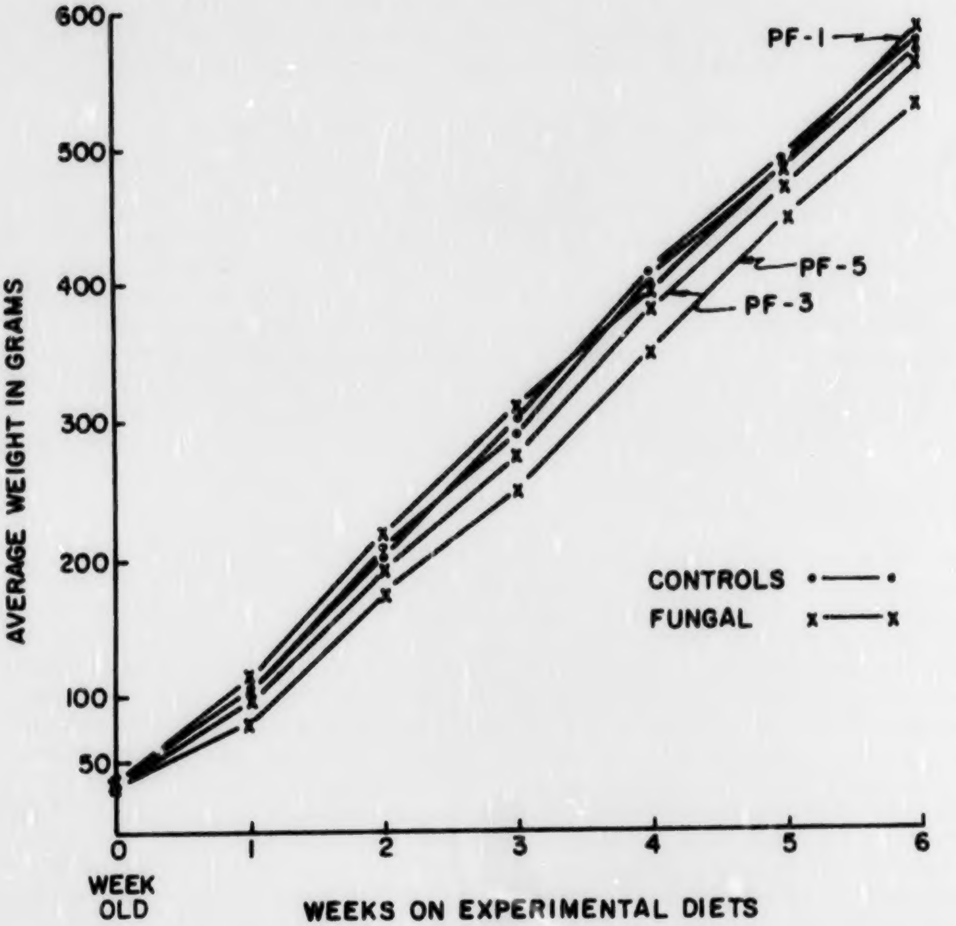


Figure 10.

CHICK GROWTH CURVES OF AVERAGE WEIGHT GAIN PER GROUP

c. Other Feeding Studies

As stated earlier, multi-generation fungal feeding studies were conducted in mice as well as piglet and gilt hog feeding studies. The mice feeding trials were done according to the Protein Advisory Group (PAG) Guidelines #6 on pre-clinical testing. Extended mouse feeding studies through 5 generations indicated that the fungal biomass (PF-1) is a nutritious source of high quality protein and that it is safe and wholesome when used as the sole source protein in these diets. Less than adequate maternal dietary protein has been associated with long-term detrimental effects in progeny more than one generation removed from the deficit (20). No such effects were observed with the fungal diet in this study.

Baby gilts were fed, starting at two weeks of age, through weaning (6 weeks) on creep diets. Only four baby gilts were fed each diet. All baby gilts were taken from the same dam litter. Following the pre-weaning feeding trial the same animals were continued on a post-weaning diet for an additional 25 days. The fungal protein was not the sole source of protein in any of these diets and consisted of 55 to 58% of the total dietary protein. Baby gilts, in the basis of weight gain and weight gain to feed intake ratio, showed similar responses compared to the control diets. The post-weaned pigs (gilts) however, showed a significant increase in body weight from the fungal diet compared to those gilts fed only the control diet. These studies showed the fungal biomass to be clearly superior to soymeal for growing pigs beyond the weaning stage.

Economic Considerations

Justification for the commercialization of an "agro-industrial" waste bioconversion and utilization process for the production of high grade protein livestock feed supplements, has significant potential for improving human nutrition in developing nations, adding to the economic development of the rural sectors in those nations, and sparing the protein reserves of the developed nations. The objective of this analysis was to determine the aggregate economic feasibility of commercial fungal waste conversion for animal feed supplements. More specifically, the objectives centered upon: (1) an estimation of the animal feed supplement market necessary to economically justify a commercial "agro-waste" installation, (2) an estimation of the potential size of an animal feed supplement market, and (3) an estimation of economic return on investment. Engineering cost data were obtained from the studies reported heren. All investment and operational cost estimates were verified through industrial sources. Plant specifications established in this report were used as the basis of analysis. Feasibility determination was comprised of standardized methods, including an analysis of break-even (that market required to cover all annual investment and operating costs) and pay-back (a measure of return on capital investment).

Based upon cost estimates in terms of 1976 U.S. dollars provided previously (5, 10), investment in "agro-waste" installations would be economically feasible for the corn wet-milling and grain processing industry. A

feasibility study centering upon "agro-waste" processing of industrial fruit and vegetable camery wastes would likely precipitate potential markets and installations.
Summarized data from these studies showed a profit margin of 1.25 cents per pound of BOD_5 waste based on the credit accrued from sale of the harvested fungal solids and equated to the prevailing soymeal price of $116/ton, was determined for the process described in this paper. Since the price of soymeal today is twice this quotation and the capital and investment costs are not twice the costs used here - the profit margin is better today than when these estimates were made in 1976. Also, the fungal biomass can replace the vitamin requirement as well as protein in animal feeds, and therefore should be more valuable a feed supplement than soymeal.

More updated estimates than those reported (5, 10) will be available in the near future based on the more efficient plant processing studies carried out in this report.

CONCLUSIONS AND DISCUSSION

Lest anyone has the impression that fungal fermentation is relatively recent or something of a novel curiosity, we refer the reader to the list of fungal food products reviewed by Hesseltine (21) where in at least one case, that of shoyu, the fermentation is over 1000 years old. Hesseltine believes that two major developments will be made in (1) the use of fungal enzymes themselves to produce desirable fermented products and (2) use of fungi on mixed substrates, i.e. combinations of cereal grains and legumes so that the final fermentation product will have a more desirable nutritional balance and the substrate mix will totally provide the carbon and nitrogen required for fermentation.

Laboratory studies, both batch and continuous, were carried out in our own developed apparatus which was designed to avoid the pitfalls inherent in commercial type equipment when used for fungal studies. Details of the fermentor will be published elsewhere.

A fungal inoculum level (10 - 20%), a low pH 4.0 to 4.5, selection of a rapid growing fungal strain, and the inoculation - dilution start-up procedure were found to be required for maintenance of a near pure culture condition. Although the waste substrates were heated during plant corn processing, they were never sterile at the time of fungal treatment. Under optimal fermentation conditions, the contaminant level rarely exceeded 200 microorganisms per ml. of the fermentation medium. In instances where contaminants were present e.q. lactobacilli, acetobacter, yeasts, an occasional protozoan, only fungal strains predominated. Fungal contaminants which constituted the most challenge during periods of equipment malfunction were found to be strains of Geotrichium, Penicillium, Aspergillus, and Mucor.

One of the more valuable observations made during these studies was in the area of balanced growth and steady-state kinetics achieved where nitrogen supplementation was in slight excess. Phosphate proved to be an excellent limiting nutrient for a balanced system! Although this was established in the laboratory studies, it was more difficult under the industrial conditions. Significant to the work, however, was in the pilot observations where substrate concentration and substrate compositional changes occurred regularly and such changes were rapidly accommodated by a rapidly changing fungal biomass density. A better balanced pilot and full-scale fermentation can be achieved than shown here by exercising more control over the nitrogen and phosphate levels.

Dilution rate changes were made at times of severe temperature shift (these were out-door systems) and, on occasion, recycling (not described in this paper) of the fungal mass was found necessary to maintain a near steady-state.

Animal feeding trials were exceedingly successful and will be described in more detail in a forthcoming publication. Other investigators working with fungal fermentation of other type waste substrates (7, 8, 12, 15, 21, 22) have also reported excellent animal feeding trials. Based on healthy animal growth together with the lack of any toxicologic developments, it appears that extensive utilization of fungal protein - vitamin feed supplements could aid in the alleviation of protein deficiency in world population groups as well as provide valuable industrial waste pretreatment.

REFERENCES

1. Sukhatme, P. V. Recent trends in world food availability and their implications, in Chavez, A., Bourges, H., and Basta, S. (ed.). "Foods for the expanding world", Proc. 9th Internat. Cong. Nutr., Mexico, 1972, Vol. 3., S. Karger, New York (1975).

2. Humphrey, A. E. Product outlook and technical feasibility of SCP, in Tannebaum, S. R. and Wang, D. I. C. (ed.). "Single Cell Protein-II", M. I. T. Press, Chapter 1., 1-23 (1975).

3. Wang, D. I. C. Chem. Eng., 26 (17), 99 (1968).

4. Lipinsky, E. S. and Litchfield, S. H. Food Technol. 28 (5): 16, (1974).

5. Church, B. D. Application of Fungi Imperfecti for treatment of cereal processing wastes. Final Report to Agricultural Research Service, Norhtern Utilization Research and Development Division, Contract Number 12-14-100-11022 (71), United States Department of Agriculture, Peoria, Illinois, (1977).

6. Imrie, F. K. E. and Vlitos, A. J. Production of Fungal protein from carob. In Single Cell Protein-II, M. I. T. Press, 223, (1975).

7. Romantsehuk, H. The Pekilo process: protein from spent sulfite liquor. In Single-Cell Protein-II, The M. I. T. Press, 344, (1975).

8. Duthie, I. F. Animal feeding trials with a microfungal protein. In Single-Cell Protein-II, The M. I. T. Press, 505, (1975).

9. Khor, G. L., Reade, A. E., and Gregory, K. F. Nutritive value of thermotolerant fungi grown on cassava. J. Inst. Can. Sci. Technol. Aliment., 9 (3): 139, (1976).

10. Church, B. D., Nash, H. A., and Brosz, W. Use of Fungi Imperfecti in waste control. Water Pollution Control Research Series, 12060 EHT, 07/70, (1970).

12. Rolz, Carlos. Use of Cane and Coffee Processing by-products as microbial protein substrates. In Single-Cell Protein-II, The M. I. T. Press, 273, (1975).

13. Methods for Chemical Analysis of Water and Wastes. Environ. Protect. Ag., Water Quality Laboratory, 16020 ... 07/71, Cincinnati, Ohio, U.S. Gov. Printing Office: 1971 0-427-263, (1971).

14. Monod, J. Annual Review of Microbiology, 3, 371-394, (1949).

15. Champagnat, A., Vertet, C., Lainé, B., and Filosa, J. Nature, 197: 13, (1963).

16. Kamazawa, M. Production of yeast from n-paraffins. Single-Cell ProteinII, Tannebaum and Wang ed., The M. I. T. Press, Cambridge, MA., 438, (1975).

17. Thomas, K. Biological value of nitrogeneous substances in different foods. Arch. Anat. Physiol., 219, (1909).

18. Allison, J. B. The efficiency of utilization of dietary proteins. In Protein and Amino Acid Nutrition, (A. A. Albanese, Ed) Academic Press, N.Y., (1959).

19. Mitchell, H. H., Hamilton, T. S., Beadler, J. R. and Simpson, F. The importance of commercial processing for the protein value of food products. J. Nutr., 29, 13, (1945).

20. Chow, B. F., Comments on prenatal malnutrition. In: Malnutrition, Learning, and Behavior. Schrimshaw and Gordon eds., M. I. T. Press, Cambridge, MA. (1968).

21. Reade, A. E. and Gregory, K. F. High-temperature production of protein-enriched feed from carsava by fungi. Appl. Microbial., 30: (6), 897, (1975).

22. Smith, R. H. Fungal enriched barley grain for pigs. Pig Farming, May, 68-73, (1972).

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WATER REUSE OF WASTEWATER FROM A POULTRY PROCESSING PLANT

by

J.B.Andelman* and J.D.Clise**

INTRODUCTION

A wastewater treatment and reclamation system has been constructed at the Sterling Processing Company in Oakland, Maryland. This plant slaughters and processes approximately 50,000 birds per day in an eight hour operation, utilizing approximately 350,000 gallons per day of treated well-water. Because of the lack of additional water of acceptable quality, the wastewater reclamation system was constructed with the intention of mixing the renovated water on a 50/50 basis with well water, ultimately increasing the quantity of water needed for an increase in production capability.

The objectives of the study reported here are to determine 1) the ability and reliability of the water reclamation system to deliver water, mixed with the well water source, that is safe for use in processing poultry; 2) if the processed poultry have any constituents harmful to human health as a result of exposure to this mixture of renovated and well water; and 3) to recommend monitoring procedures and parameters needed to insure the safety of the system and the protection of human health.

This project is important as a demonstration of the technical and economic feasibility in the food industry of moving towards the national goal of limiting discharges into navigable waters. Water re-use is an important strategy in achieving this goal. However, in such re-use of water involving human consumption or exposure, it is mandatory that the health of the consumer be protected. If this project can successfully demonstrate that the renovation process can deliver a safe and potable water, and that the poultry processed with the water similarly pose no threat to human health, this will constitute an important step in our overall effort towards reducing emissions to the nation's waterways.

APPROACH

An initial study of the feasibility of reclaiming poultry processing wastewater for reuse at the Sterling plant was reported by Clise (1). The reclamation

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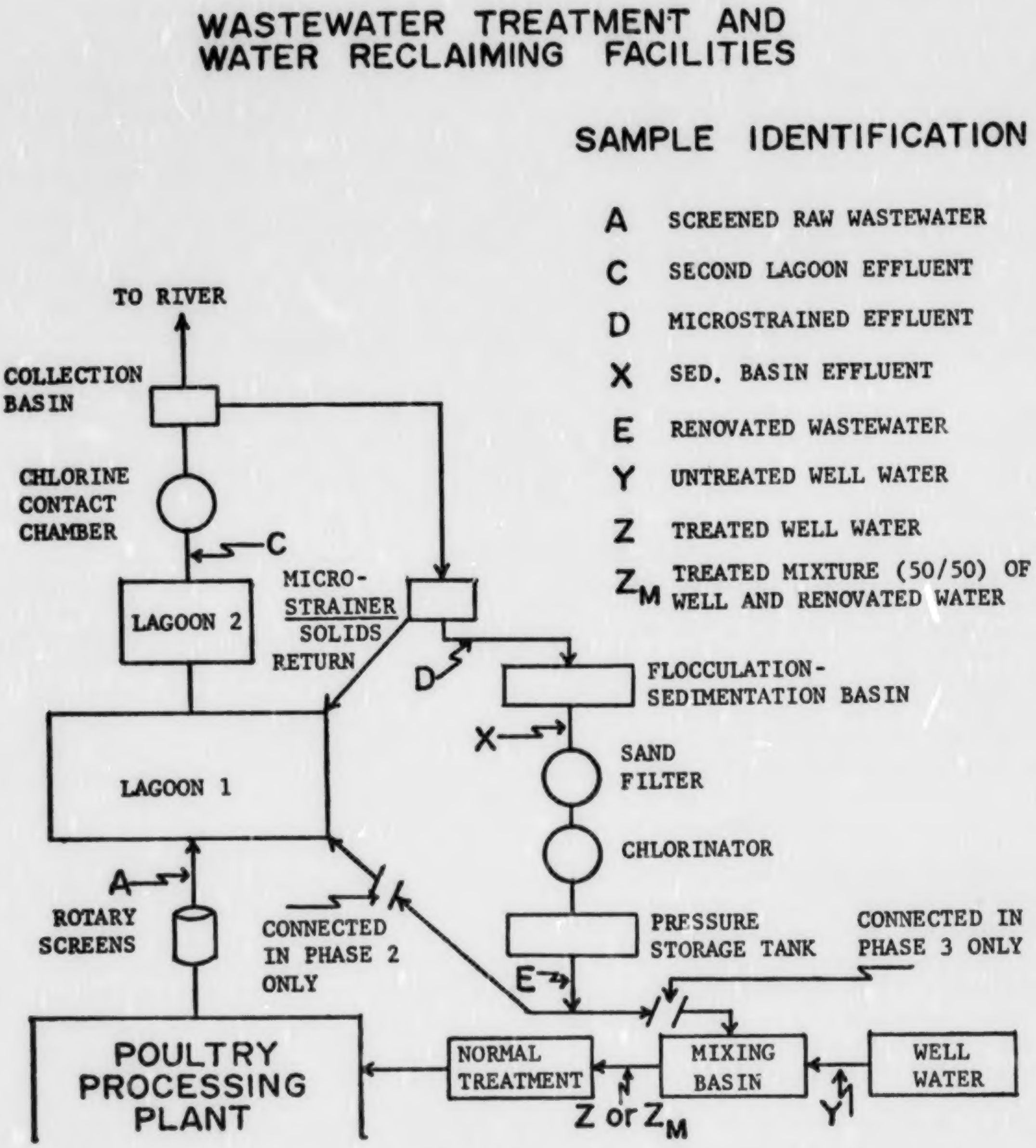
system consisted of aerated lagoons, followed by microstraining, flocculation and sedimentation, and filtration, with two stages of chlorination. The schematic of the system is shown in Figure 1. The initial study showed that the reclaimed water met U.S. Public Health Service 1962 Drinking Water Standards for chemical, microbiological and physical constituents without actual recycle through the poultry processing plant. Nevertheless, there was concern that with actual reuse there was the possibility that unmeasured constituents, such as pathogenic microorganisms, heavy metals, pesticides and toxic organic chemicals, might build up in recycle and be absorbed by the carcasses in the processing plant.

An additional project was proposed by the Maryland State Department of Health and Mental Hygiene and funded by the E.P.A., the purpose of which was to modify and optimize the reclamation system, to determine the capability and reliability of the system for delivering water satisfactory for processing poultry, and to evaluate the exposure of the processed carcasses to constituents that could be harmful to human health. The role of the Graduate School of Public Health, University of Pittsburgh, was to design, organize, and supervise the sampling and analytical part of the study, as well as evaluate the results from the points of view of both the quality of the renovated water and the processed poultry possibly affected by it. Three phases were planned in this study, the first two of which have been completed. Phase 1 involved the operation of the reclamation plant with a new sand filter, and measurement of those characteristics pertinent to optimizing the process. Phase 2 involved a study of a wide range of physical, chemical and microbiological constituents, both at various points in the reclamation system, as well as in processed carcasses exposed to renovated water, but without actual recycle through the plant. Phase 3 was to involve recycle of the renovated water into the processing plant by mixing on an average 50/50 basis with well water, the mixture then to undergo additional full-scale conventional treatment. The carcasses were again to be measured, as was the renovated water, and comparisons made of the levels of contaminants with those in normal plant operation utilizing well water only in Phase 2.

Prior to proceeding to Phase 3, an evaluation was made of the Phase 2 results by a committee consisting of representatives of the E.P.A., the Maryland Health Department, the processing plant, the U.S. Department of Agriculture, and the Graduate School of Public Health. The level of contaminants in the treated wastewater and processed carcasses were considered as to their possible health significance. A similar evaluation was to be made following Phase 3 so as to determine the safety of proceeding to continuous operation with reclaimed wastewater. Finally, recommendations were to be made as to the need for continuous monitoring of the system.

This paper reports primarily the principal results of the Phase 2 study and some additional measurements obtained subsequently. Phase 3, the actual recycle of the renovated water into the processing plant for a trial three-month period, has not been instituted, even though the above Committee, constituted for the purpose, recommended that there was no significant risk in so doing. Some of the background and reasons for this delay will be discussed subsequently.

FIGURE 1. WATER SAMPLING POINTS AND CONNECTIONS FOR PHASE 2 AND PHASE 3 STUDIES


WASTEWATER TREATMENT AND WATER RECLAIMING FACILITIES
SAMPLE IDENTIFICATION
A SCREENED RAW WASTEWATER
C SECOND LAGOON EFFLUENT
D MICROSTRAINED EFFLUENT
X SED. BASIN EFFLUENT
E RENOVATED WASTEWATER
Y UNTREATED WELL WATER
Z TREATED WELL WATER
Z_M TREATED MIXTURE (50/50) OF WELL AND RENOVATED WATER
TO RIVER
COLLECTION BASIN
CHLORINE CONTACT CHAMBER
C
LAGOON 2
MICRO-STRAINER
SOLIDS RETURN
D
FLOCCULATION-SEDIMENTATION BASIN
X
SAND FILTER
CHLORINATOR
LAGOON 1
A
ROTARY SCREENS
CONNECTED IN PHASE 2 ONLY
PRESSURE STORAGE TANK
CONNECTED IN PHASE 3 ONLY
E
POULTRY PROCESSING PLANT
NORMAL TREATMENT
MIXING BASIN
WELL WATER
Z or Z_M
Y

NATURE OF STUDY

Following the optimization of the operation of the water renovation system (Phase 1), the two-month study of Phase 2 was performed. This involved seven separate days of sampling, approximately once a week in the Spring of 1976. Two preliminary sampling trips were conducted to optimize sampling at the site. On each of these days various water and wastewater samples were collected. In addition, twenty-five carcasses were collected for analysis from the plant chiller system. Finally, a small "experimental" chiller was set up to simulate the plant chiller. Twenty-five carcasses were taken from the plant, prior to exposure to the plant chiller, and placed in the experimental chiller in such a way and for such a period as to simulate the plant chiller. However, the experimental chiller was filled with renovated water. The purpose was to analyze and compare the possible build-up of contaminants in carcasses exposed to the plant chiller using normal, treated well-water, versus those exposed to the experimental chiller using renovated water. It must be emphasized that at no time during Phase 2 was renovated water ever used in the processing plant.

Figure 1 shows the schematic of the wastewater renovation system, the connections for Phases 2 and 3, and the possible sample points to be utilized in the study. The actual Phase 2 sampling points and the number of samples taken on a typical sampling day are shown in Table 1.

Not all of the sampling points were subject to all the analyses. The types of analyses that were to be performed are shown in Tables 2 and 3. Table 2 lists the Category I analyses. As shown there, Categories Ia, b, and c were to be performed only on water samples, while Id was to be done on carcass samples as well. In fact, some Ia and Ib analyses were performed on carcasses.

Table 3 shows the Category II and III analyses. As noted there, all of these analyses were to be done on both water and carcass samples. All were performed, with the exception of the halogenated methanes of Category III. These were done subsequent to Phase 2, and will be reported here.

Although analyses of viruses were not contemplated originally in this study, the decision was made to attempt to measure an avian virus and use it as an indicator or sentinel of the behavior of other viruses in the water renovation system. Since it was reported that the chicken flocks were routinely inoculated with attenuated Newcastle Disease virus (NDV), it was decided to develop the methodology and sample the water and carcasses for it. The results of this investigation will be reported. In addition, some laboratory die-off studies were performed using lagoon water spiked with NDV.

Finally, and subsequent to Phase 2, total organic carbon measurements (TOC) were performed on the renovated water, the normally treated well water, and that taken at other selected sampling points. In addition, a few samples of the treated well and renovated water were analyzed by gas-chromatography-mass spectrometry (GC-MS) for some specific organics, other than those shown in Table 3.

Table 1. PHASE 2 SUMMARY OF TYPES OF SAMPLES TYPICALLY TAKEN FOR ANALYSIS EACH WEEK

Water Samples

Location	Maximum Number per day
A - Raw Waste	2
E - Renovated Water	2
Z - Treated Well Water	2
PC - Plant Chiller	2
EC - Experimental Chiller	2

Birds (Carcass Samples)

PB - Plant Chiller Birds	5*
EB - Exp. Chiller Birds	5*

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*50 carcasses were taken for analysis each sampling day, 25 PB and 25 EB. In each case washings from 5 carcasses were composited or otherwise combined to become a single carcass sample. Hence, 25 carcasses reduced to 5 samples.

Note - Occasionally water samples were taken at other sample points shown in Figure 1 or within the lagoons.

Table 2. WATER RE-USE PROJECT

Types of Analyses to be Performed

Category I Analyses

Ia - These analyses relate primarily to waste treatment efficiency and none will be performed on carcasses

BOD_5

Grease

Organic nitrogen

Ammonia nitrogen

Suspended solids

Total solids

Alkalinity

Ib and c - These analyses relate to waste treatment efficiency and potable water quality; none will be performed on carcasses

Ib

Turbidity

Color

Total Dissolved solids

Residual chlorine (total)

Residual chlorine (free)

Ic

CCE (carbon chloroform extract)

Id - These analyses relate to waste treatment efficiency and water quality. They will be measured for water and carcass samples.

Total plate count

Total coliform

Fecal coliform

pH

Table 3. WATER RE-USE PROJECT

Types of Analyses to be Performed

Category II Analyses

These analyses will be performed on water and carcass samples

Salmonella (enumeration)

Drug residual

Category III Analyses

These chemical analyses will be performed on water and carcass samples

Arsenic
Barium
Cadmium
Calcium
Chloride
Chromium
Copper
Cyanide
Fluoride
Halogenated methanes
Hardness
Iron
Lead
Magnesium
Manganese
Mercury
MBAS
Nitrate
Potassium
Selenium
Silver
Sodium
Sulfate
Zinc
Pesticides

METHODOLOGY

Except where noted below, all analytical methodology is consistent with that specified by the E.P.A. or Standard Methods for the Examination of Water and Wastewater (14th Edition). All necessary precautions for transporting the samples, such as refrigeration or the addition of chemical preservatives, were taken.

The experimental chiller using renovated (E) water was operated on a batch basis. That is, it was filled with renovated water and plant-made ice was added to bring the temperature initially to about 55°F. The 25 carcasses were then lowered into the bath within the drum and rotation begun. Additional ice to maintain 55°F was added. Approximately 15 minutes later more ice was added to reduce the bath temperature to about 34°F, and chilling continued for another 10 minutes.

The carcasses were removed by handling with clean plastic gloves, and both plant and experimental chiller carcasses were treated in the same fashion. They were placed, after draining, in either clean or pre-sterilized (by autoclaving) plastic bags and carried to the laboratory trailer. 1500 ml of either distilled or distilled and sterile water was added to each such bag, which was then shaken for one minute and the water contents poured for analysis.

Salmonellae were isolated from the water and poultry samples using membrane filtration techniques modified from the recent literature. Quantitation of salmonellae was attempted employing 15 dilution tubes to determine the most probable number (MPN) index of organisms. Subsequent to the Phase 2 study our research on media selective for salmonellae developed to the point of being able to quantify by this technique. In the Phase 2 results, however, only their qualitative presence or absence are reported.

A disc assay method modified from the procedure of Huber et al. (2) was employed to detect residual drugs in the water and carcass samples. The first method used in this laboratory employed Bacillus subtilis (Difco spore suspension containing approximately 10^{10} spores/ml) as the test organism and seed agar (antibiotic medium No. 1) as the test substrate. This procedure was further modified according to the method of Read et al. (3) in order to detect bacitracin and to enhance the sensitivity of detecting sulfa drugs and antibiotics in the water and carcass samples. Bacillus cereus and Mueller-Hinton agar were thus employed as the test organism and the test substrate, respectively.

Primary chick embryo cell cultures were used with a plaque assay to detect the presence of avian viruses in the water and carcass samples, which were first filtered through 0.45 micron pore-size membrane filters. Following inoculation of the cell monolayers with the filtered samples and various incubation procedures, plaques were counted and the plaque-forming units per ml (PFU/ml) determined. In order to detect the possible presence of such viruses in the carcasses, tissue extracts were prepared from spleens, lungs and livers, processed and analyzed for the presence of avian viruses, such as NDV, capable of hemagglutinating chicken red blood cells.

RESULTS

Most of the individual analytical results will not be presented. Rather, for the purpose of this paper and wherever possible, results will be summarized or presented in statistical fashion.

Microbiological and Drug Residual

Neither salmonellae nor any other Enterobacteriaceae were ever isolated in the chlorinated renovated (E) or well water (Z). The carcasses exposed to and the water from the experimental chiller, using the renovated water, were similarly negative in this respect. Salmonellae was isolated in raw wastewater (A). However, the aerated lagoon and renovation system was completely efficient in disinfecting this bacterium.

All samples tested for drug residual using both Bacillus subtilis and Bacillus cereus were negative. Thus, this test has not detected any antibiotic drug in either the water or carcass samples.

Similarly, avian viruses, including NDV, have not been detected either in the water or carcass samples, nor in tissue extracts from chickens processed at the Sterling plant. Only preliminary results of the NDV laboratory die-off experiments using lagoon water can be reported at this time. These samples, spiked with NDV, were studied for up to seven days at two temperatures, in the light and dark. There was no apparent effect of light. At 25°C die-off was complete (indicated by the absence of plaque-forming units in the assay) after 3 days. At 7° C, however, the die-off was very slow, less than a factor of 10 in one week. These experiments are continuing, particularly to elucidate the possible role of particulate matter in the lagoons in virus survival.

The renovated water (E) was analyzed for bacteria on eight days during and just prior to the Phase 2 period, 19 samples being taken. On six of the eight days the total and fecal coliform results were less than 2 organisms per 100 ml. On April 5 and 12 four E samples were analyzed. The reported total coliform ranged from 15 to > 240 organisms per 100 ml, and the fecal coliform from 9 to > 240. However, there is a strong likelihood that these E sample results were confused with those of EC, the experimental chiller water. The results for the latter for those two weeks were reported as negative for coliform and fecal coliform, a highly unlikely result compared to all other EC and PC coliform analyses, which were >240.

The total bacterial plate count analyses on the samples described above indicated a maximum value of 25 organisms per ml for the Z samples and 15 for E, except for the four samples which are believed to be incorrect. For these latter four, the values ranged from 1 to 2,000. A reasonable maximum total plate count for municipal water is 500 per ml.

In view of the high probability that the inadequate bacterial quality of the four E samples was due to sample reporting error, and that no E samples have yielded any enteric pathogens, it is concluded that the renovated water is of excellent bacterial quality. It should also be noted as well that in actual recycle the E water will receive additional treatment, including chlorination, after being mixed 50/50 with the untreated well water.

Inorganic Chemical Water Quality

A summary of the results for several macro constituents and water quality characteristics for Z and E is presented in Table 4. Other than pH, alkalinity, and nitrate, the mean concentrations of all these parameters were higher in the renovated water, E, than in the treated well water, Z. However, these concentrations in E are not hazardous, and only one maximum value shown, 252 mg/l for sulfate, is at the criterion level, which has only been a secondary standard. This sulfate buildup is not of concern, but could be reduced, since it is primarily due to the alum coagulant.

It should be noted that some of the differences in the mean concentrations of chemicals in Z and E are not statistically different when the variability of the results are considered. Thus, color cannot be considered to be statistically different in the Z and E water. However, there is unquestionably a build-up of dissolved macro constituents in the renovated water. This is not unexpected and, at the levels encountered, does not pose a health hazard.

Attention should be called, however, to the low alkalinity in E, and the low pH values. On some days the pH was as low as 3.3 due to the large doses of chlorine. The E water will be mixed with untreated Z in Phase 3, which will mitigate this problem. However, to avoid corrosion in the system, soda ash or caustic soda has been added to raise the pH and alkalinity when required.

Table 5 presents a comparison for Z and E for certain measurements related to waste treatment parameters. The total solids in E are obviously higher than in Z, but this is due to the dissolved solids already discussed. The organic nitrogen values for E reflect its higher organic content.

Of some interest and possible concern among the constituents reported in Table 5 is the relatively high average concentration of ammonia nitrogen in the renovated water. It probably results from biological denitrification reactions in the lagoons, although some concentrations measured in the raw waste are comparably high. The principal concern is that the ammonia reacts with the chlorine disinfectant to form chloramines, which are less effective disinfecting agents. However, because of this very reaction, unless the samples are analyzed immediately, it is unlikely that with the practice of breakpoint chlorination the ammonia should have been detected. Subsequent to Phase 2 the ammonia concentrations in E decreased considerably. It should be emphasized that the excellent bacterial quality of E water indicates that disinfection has not been affected. Also the presence of these concentrations of ammonia is not known to be a health hazard. Finally, it is noteworthy that ammonia is sometimes added in municipal water treatment plants in order to react with chlorine and form longer-lived chloramines.

A summary of the results for the trace constituents in Z and E waters is shown in Table 6. It should be emphasized that the concentration units here are micrograms per liter. All of the maximum concentrations were well below

Table 4 . PHASE 2 - WATER QUALITY CHARACTERISTICS AND MACRO CONSTITUENT CONCENTRATIONS*
(in mg/1, except where noted)

	Treated Well Water (Z)				1962 PHS Criterion Value	Renovated Water (E)			
	N	$\overline{X}$	σ	Max		N	$\overline{X}$	σ	Max
Turbidity (JTU)	6	0.9	0.5	1.7	5	35	1.6	1.7	2.7
Color (units)	6	3.0	1.6	5	15	36	3.7	3.3	10
pH	12	7.0	0.2	7.2	-	30	5.8	1.4	6.9
Alkalinity	12	107	15	130	-	15	35.3	37	140
Chlorine Res.	-	-	-	-	-	52	1.7	1.3	6.0
Surfactants (MBAS)	14	<0.01	-	-	0.5	13	0.04	0.02	0.08
Na^+	14	7.4	3.4	12.5	-	14	30.2	12.5	47.7
K^+	16	2.9	3.6	8.7	-	15	14.7	2.3	17.4
Ca^{++}	16	40.1	4.8	49.4	-	16	53.7	5.8	64.9
Mg^{++}	16	2.4	0.3	2.9	-	15	2.95	0.3	3.4
Cl^-	12	11.6	1.0	13.4	250	12	88.5	16.8	121
NO_3^-	8	4.0	0.6	4.9	45	8	3.5	1.5	6.2
SO_4^{--}	8	9.6	3.6	13.5	250	8	150	85.6	252
HCO_3^-(est)	-	130	-	-	-	-	43	-	-
Ion Total		208					393		
Dissolved Solids	12	143	33.8	194	500	16	389	66	492

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*Occasionally extreme values (beyond 2σ) discarded

Table 5

PHASE 2 - CERTAIN WATER CHARACTERISTICS RELATED PRIMARILY TO WASTE TREATMENT EFFICIENCY (in mg/l)

	Treated Well Water (Z)				Renovated Water (E)			
	N	$\bar{X}$	σ	Max	N	$\bar{X}$	σ	Max
Total solids	12	165	33	234	13	418	72	501
Suspended solids	12	10.4	8.1	26	14	16.8	19.7	70
BOD_5	12	5.3	4.3	18	14	3.4	2.2	7.0
Grease	12	5.2	6.1	23	13	5.1	4.8	18.2
Organic-N	8	0.013	0.008	0.030	10	1.7	1.5	5.0
Ammonia-N	8	0.017	0.013	0.040	10	19.0	4.4	23.0
Dissolved Oxygen	12	8.1	0.6	9.4	14	9.3	1.4	11.7

Table 6. PHASE 2 - TRACE CHEMICAL CONCENTRATIONS* (μg/l)

	Treated Well Water (Z)				PHS 1962 Criterion Value	Renovated Water (E)			
	N	$\bar{X}$	σ	Max.		N	$\bar{X}$	σ	Max
Cu	16	41.4	11.2	57	1000	14	38.8	12.9	56
F	14	58	33	13	1000	14	151	54	230
Fe	16	19.2	7.8	31	300	14	57.1	24.3	98
Mn	16	1.8	1.0	3	50	14	2.6	1.0	4
Pb	16	21.2	16.7	50	50	15	23.8	13.9	50
Zn	12	25.2	3.8	33	5000	12	27.2	6.9	38

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*Occasionally extreme values (beyond 2σ) were discarded the PHS criterion values, except for lead in both E and Z samples. These were not significantly different for the two waters, and the high concentrations in each case were just about at the criterion value. Only in the case of iron and fluoride were the concentrations significantly higher for E compared to Z. However, it is judged that for none of these six trace elements were there any hazards in the renovated water.

Although not shown in Table 6, all the measurements for silver, arsenic, cadmium, chromium, and selenium were negative (below the sensitivity levels). About half of the E samples were positive for cyanide at concentrations up to 12 μg/l, but well below the health criterion value of 200 μg/l. It is difficult to imagine any oxidizable cyanide being present in E because of the large quantities of added chlorine. However, the analysis was for total cyanide, so that the measurement may have detected such harmless combined complexes as those involving iron, often used as an anti-caking agent, such as in road salt. Several water samples were positive for mercury. These occurred in three of the eight weeks, two of which were analyzed on the same day. It is likely that in the latter cases there was contamination or analytical error, perhaps as a result of the mercury preservative added to the nitrate sampling bottle. On two subsequent weeks when this possibility was removed, only one out of six E samples were positive (0.6 μg/l), and no Z samples. In contrast, during the previous two weeks E, Z and all other samples were positive and much higher. For the samples of the first four weeks none of the E or Z samples were at concentrations higher than 0.2 μg/l, the level of sensitivity of the method. In view of the fact that the highest E sample was 1.7 μg/l, even though it was probably an erroneous reading due to contamination, and the fact that the criterion value is 2 μg/l, it may be concluded that there is no observed health hazard from mercury in the renovated water.

Carcass Chemical Analyses

The results of the chemical analyses of the washings from the carcass samples PB, from the plant chiller, and EB, from the experimental chiller, will be summarized here, but not tabulated. Most of the chemical species analyzed in water, as shown in Tables 4, 5, and 6, were also analyzed in the carcass washings. Among the macro constituents only the mean nitrate concentrations were statistically significantly higher at 0.38 mg/l in the EB samples compared to 0.06 in PB. The reason for this difference is not known, since the Z and E waters are not significantly different in nitrate concentrations, as shown in Table 4. It is very unlikely that this poses any kind of a health hazard. Taking the mean value of 0.38 mg/l of nitrate in the EB samples, and assuming that this all came from the carcasses, since 1.5 liters of distilled water was used to elute the carcasses, this would be equal to 1.5x0.38, or 0.57 mg nitrate per carcass. This is not a quantity of concern in the perspective, for example, of the current primary drinking water regulation, which permits an average daily adult ingestion of about 90 mg nitrate.

The mean values of all the waste characteristic and trace element measurements were the same, within statistical confidence, for the PB and EB samples in Phase 2, with the exception of ammonia nitrogen. The mean EB value was 1.1 mg/l, while that of PB was 0.09. This result is most probably attributed to the high ammonia content of the renovated water, but cannot be considered to be a health hazard.

Organic Water Quality

A variety of measurements of gross organic parameters and specific organic chemicals have been performed during and subsequent to Phase 2. These include BOD_5, organic nitrogen, and CCE (carbon chloroform extract), as Category I analyses, shown in Table 2; halogenated methanes, MBAS (surfactants), and pesticides, as Category III analyses, Table 3; total organic carbon (TOC); and specific organics extracted with methylene chloride and identified by gas chromatography-mass spectrometry (GC-MS).

A comparison of the mean results for the surfactants, shown in Table 4, indicates significantly higher concentrations in the renovated water, E, compared to the treated well water, Z. However, both the mean concentration of 0.04 mg/l and the maximum of 0.08 are well below the 0.5 mg/l 1962 PHS criterion value.

The BOD_5 summary values are shown in Table 5, indicating a somewhat lower mean value for the E compared with the Z water, although the difference is not statistically significant. In contrast, the average for the organic nitrogen, defined as the organically bound nitrogen in the negative-three oxidation state, is higher in the E water at 1.7 mg/l than that of Z, 0.013. It also shows considerable variation. It most probably consists of protein material and its breakdown products, such as amino acids, from the chickens.

Analyses were performed for nine pesticides, samples being collected on three separate days in a three-week period. These analyses were discontinued when all samples from the second and third days were negative. The results are summarized in Table 7. No positive values were obtained for the E or Z samples, only for A, the raw waste, and PB and PC, the carcasses and chiller water in the plant. The total number of E samples analyzed was nine.

A summary of the total organic carbon (TOC) analyses of samples taken on five successive weeks in November and December, 1976 is shown in Table 8. Each individual TOC value is a result of at least two measurements on the same sample, the TOC being the difference between the total carbon and the inorganic carbon analyses. The total number of samples for Z, E, X, and C shown in Table 8 were 10, 8, 6 and 4, respectively. Two samples each were measured at each of the other sampling points. These results show that there was a considerable reduction in TOC through the lagoon and then the renovation system. Although the mean value for the renovated water, E, was about 5 mg/l higher than that for Z, the treated well water, they each showed considerable variability, as indicated by their respective ranges and standard deviations.

Several carbon chloroform extract (CCE) measurements were made, both during Phase 2 and at other times, the results being shown in Table 9. These measurements were done by the newer miniaturized two-day sampling technique (4), for which a standard had been proposed of 0.7 mg/l compared to the 0.2 value for the older technique in the 1962 PHS standards. In fact, it was shown in a comparison of the two techniques that the newer method measures about 6.7 times

Table 7. Pesticides Analyzed and Found (μg/l)

Pesticide	Sensitivity Limit	Criterion* Value	Positive Values
Chlordane	0.2-1	3**	-
Endrin	0.1	0.2	0.1 (A, PB)
Heptachlor	0.06	0.1**	0.09-0.4 (A, PB, PC)
Hept. Epoxide	0.1-0.2	0.1**	-
Lindane	0.06	4	0.04-0.14 (A, PB, PC)
Methoxychlor	0.5-1	100	-
Toxaphene	3-6	5	-
2,4-D	0.05-1	100	-
2,4,5-T	0.5-1	10	-

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*E.P.A. National Interim Primary Drinking Water Regs., except for:

**Proposed as above, but not adopted

Table 8. Total Organic Carbon (TOC) Analyses of a Few Samples in Fall 1976 at the Sterling Plant

Sample Point	Concentrations - mg/l		
	Mean	Stand. Dev.	Range
Z - treated well water	14.5	7.0	6 - 26
Effluents from:			
L_1 - lagoon 1	50.5	2.2	49 - 52
C' - lagoon 2	35.0	1.0	34 - 36
C - lagoon 2 (chlorinated)	38.8	4.9	35 - 45
D - microstrainer	39.8	7.4	35 - 45
X - sedimentation basin	22.4	3.2	19 - 29
E - renovated water	20.0	5.1	15 - 31

Table 9. Carbon Chloroform Extract Concentrations (CCE) at the Sterling Renovation System

1976 Week Sampled	CCE - mg/l
Untreated Well	
3/8	0.58
Renovated Water	
3/15[a]	0.96
3/29	1.2
4/19	1.5
5/17	0.18
6/14	0.36
7/12	0.22
7/26	0.58 0.61
11/15	0.52
Renovated Water - Mean	0.68
Standard Dev.	0.45

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a - stored water

as much CCE as the older one (4). The results in Table 9 indicate considerable variability in the CCE values in the renovated water, E, but these values overlap with and on the average are not very different from the single measurement of the untreated well water.

On four successive weeks in November and December, 1976 volatile halogenated methanes were measured, essentially using the technique of Bellar and Lichtenberg (5). The only organic found by this technique in the renovated water, E, was chloroform, the maximum concentration being 3 micrograms per liter. In some of the treated well water samples, Z, chloroform was measured at concentrations of less than one microgram per liter, and one showed traces of carbon tetrachloride and dibromochloromethane. For reference, the mean chloroform concentration in finished U.S. public water supplies was reported to be 21 micrograms per liter in the National Organics Reconnaissance Survey (6).

Finally, samples of E and Z water collected on two separate days subsequent to Phase 2 were extracted by methylene chloride, concentrated by evaporation and analyzed by GC-MS for specific organics. Three general types of compounds were identified by this technique. At the moment, the analyses have not yet been confirmed with standards. In the renovated water, E, the following normal fatty acids were identified: C-10, -11, -12, -14, -15, -16, and -18; in the treated well water, C-12, -14, -16, and -18. None of these contain chlorine atoms. In the renovated water dioctyl and dibutyl phtalate were identified, but only the former in the treated well water. Both of these compounds are used as plasticizers and have been widely found in a variety of waters, including potable municipal supplies (7).

The most unusual set of compounds that was found in all of the E and Z samples, analyzed by GC-MS, consists of five organics that appear to be halogenated or hydrohalogenated derivatives of cyclohexene. They are: 3-chlorocyclohexene, 2-chlorocyclohexanol, 1,2-dichlorocyclohexane, 1-bromo-2-chlorocyclohexane, and 2-bromocyclohexanol. Only one U.S. company manufactures cyclohexene, the presumptive parent compound, in any significant quantity, and it has very specialized uses. In view of this and the fact that such uses are unlikely in the vicinity of the Sterling plant, it is also highly unlikely that it is a contaminant either of the ground water source or from the poultry plant operation. Recent evidence developed elsewhere seems to indicate that it, or the halogenated derivatives, are probably contaminants of the chlorine used for disinfection. Some of these compounds have recently been found in two municipal water supplies, probably from the chlorine used in the treatment process. This situation is being investigated.

DISCUSSION

The focus of this discussion will be whether the quality of the renovated water, E, is sufficient to justify its reuse in processing poultry at the Sterling plant, without risking the health of the consumers. It should be emphasized in this discussion that, prior to actual use in the plant, the renovated water will be mixed 50/50 with the untreated well water, then receive the normal water treatment that is currently utilized for it. This consists of prechlorination in the mixing basin, alum-lime flocculation, with final pH adjustment to precipitate iron, settling, and filtration through two sand filters. Additional chlorine is introduced into the main service line leading to the processing plant for residual control.

The principal operation in the processing plant that exposes the carcasses to water is the chiller, which precedes the icing and packaging of the processed meat. Each carcass can take up as much as 10 per cent of its weight in water in this operation. The chiller is a continuous, countercurrent system which itself rapidly accumulates contaminants in the course of a day's operation (8). The evaluation of the renovated water, E, studied in Phase 2, should be done in the perspective of the further treatment it will receive in actual reuse, as well as the intended use of that water. In that use the most important water exposure of the poultry being processed in the chiller operation.

The microbiological quality of the renovated water, E, studied in Phase 2 is excellent. No pathogenic bacteria were detected in that water. Aside from some confusion, probably from mislabeling of samples, all the coliform and fecal coliform concentrations were below the level of detection. The total plate counts were also low. Avian viruses were also not detected in the renovated water. In view of the approximately two-week's detention time in the aerated lagoons and the nature of the disinfection processes subsequent to them, which involve two stages of chlorination, this excellent microbiological quality is to be expected. With actual recycle into the plant, this high quality and the additional treatment, including disinfection, would insure, with a high degree of certainty, that there would be no danger from pathogenic organisms in the reuse of this renovated water.

The inorganic water quality of the renovated water studied in Phase 2 is also quite good. As would be expected, several of the major cations and anions are significantly higher in the renovated water than the normally treated well water. Such build-ups are common, since typical waste and water treatment processes are not designed for, nor capable of removing significant quantities of these materials. The concentrations of these constituents in the renovated water, shown in Table 4, do not constitute a health hazard in water reuse.

The trace elements and waste parameters shown in Tables 5 and 6 are also not at levels that are of concern, were the renovated water actually reused as contemplated. The trace elements are not significantly different for the renovated and normally treated well water, with the exception of cyanide, fluoride, and iron. All of these are, nevertheless well below criterion levels in the renovated water. One can justifiably conclude, therefore, that, as with the microorganisms, the inorganic constituents of the renovated water do not pose a risk to human health in the actual planned recycle system. This conclusion is reinforced by the comparison of the analyses of the carcasses processed normally in the plant chiller and those exposed to renovated water in the "experimental" chiller. Among all the macro and trace inorganic constituents, only ammonia and nitrate were higher in the carcasses processed with renovated water, but not at concentrations that would constitute a health hazard.

The organic chemical quality of the renovated water at the Sterling plant remains perhaps the greatest area of possible concern, as it does for the municipal water supply systems of the U.S., principally because of the recent advances in our ability to identify and quantify trace organic chemicals at very low concentrations. Several specific organic chemicals have been identified and some quantified in this study. As noted previously, pesticides were not found in either the renovated or treated well water. Surfactants in the former were well below criterion levels. Several fatty acids were found in the renovated water, but also in the treated well water. In any event, these constitute no human hazard. The maximum concentration of the only halogenated methane found in the renovated water, chloroform, was three micrograms per liter, well below the approximate median value of 20 found in the E.P.A. National Organic Reconnaissance Survey of U.S. public water supplies (6). Two phthalates were found in the renovated water, and one of these in the treated well water. As noted perviously, both of these, widely used as plasticizers, have been found in potable U.S. municipal water supplies, as well as many natural waters.

The unusual halogenated and hydrohalogenated derivatives of cyclohexene, found in both the renovated and treated well water, in all probability are contaminants of the chlorine used in disinfection. They have been found in finished municipal water supplies and are unrelated to the renovation system. That is, it is quite likely that changing to a different source of chlorine will eliminate their presence.

It is a reasonable judgment therefore, that the specifically identified organic chemicals arising from this waste renovation process do not constitute a human hazard were this water to be used as contemplated in full recycle. One might nevertheless raise the question of the possible health hazard from organics not yet identified. It is unlikely that, in terms of the reuse of this water for processing poultry, such organics would be hazardous, since they arise primarily and originally from the poultry wastes and are likely to be only natural materials and their degradation products. A possible question concerns the reaction of chlorine with these materials to form hazardous by-products. This concern is difficult to address. It should be pointed out, however, that chlorination is practiced in certain food processing, and has probably not been associated with any ill effects in humans.

The measured gross organic parameters, namely BOD, CCE, TOC, and organic nitrogen, are also of interest as indicators of specific organic constituents. The higher organic nitrogen in the renovated water most probably reflects the proteinaceous material and its breakdown products from the poultry, but only those constituents that are not readily biodegradable, since the BOD values for the renovated and treated well waters were quite comparable. The mean BOD value of 3.4 mg/l for the renovated water is not untypical of many raw surface waters that are used for municipal water supplies, such as Minneapolis and St. Cloud (9).

The mean TOC values for the renovated and treated well water, 20 and 14 mg/l, respectively, are perhaps somewhat high, but not unusually so. The statewide average for the major Minnesota rivers is 20 mg/l, with several large municipal supplies utilizing them as raw water supplies (9). Similarly, most of the larger rivers there have concentrations of 15 to 30 mg/l. In a study of 80 municipal water supply systems of the U.S., non-volatile TOC concentrations as high as 19 mg/l were measured in the raw water and 12 mg/l in the finished water (6). About 98 per cent of the latter were less than 5 mg/l. This indicates that, in terms of a finished water supply, the renovated water TOC values are undoubtedly high. However, after mixing 50/50 with the raw well water and then full scale treatment, the final mixture should not be significantly different in TOC than the currently used treated well water.

The CCE measurements of the finished water show considerable variability. However, time variations, seasonal or otherwise, are also common in finished municipal water supplies (4). Similarly, concentrations of 1.0 mg/l of CCE are not uncommon in finished water supplies, and concentrations considerably higher than this have been found in rivers. The average concentration of 0.7 mg/l for the renovated water system had been recently proposed as a criterion value for public water supplies.

One can reasonably conclude that the organic water content of both the treated well water and the renovated water is somewhat high. Nevertheless, no specific organics in the renovated water have been found at high enough concentrations for the renovated water to be considered a significant risk to human health. At the same time, the most likely non-hazardous nature of any incremental organic material not yet identified in the renovated water is such as to reinforce that judgment.

An evaluation of many of these results was performed immediately following the completion of Phase 2 by a committee constituted to do so and make a recommendation about proceeding to Phase 3, a three-month trial period of full recycling through the plant and water reuse. That committee did not at the time have access to some measurements of organic water quality which were done subsequent to Phase 2, including most of the CCE analyses, and all of the TOC and specific organics, other than pesticides. The committee recommended that there was no significant risk in proceeding to Phase 3. We conclude that the additional data on organic chemical quality should not modify that judgment.

Nevertheless, the final decision to proceed to Phase 3 was not and has not been made as of this writing. The delay arose because of the requirement of the Department of Agriculture that the water to be reused in the plant be designated as potable. There are differing opinions as to whether it could be so regarded. The concerns center around two areas. First, is the chemical and microbiological quality of the renovated water sufficient to meet criteria of potability? In terms of meeting constituent limits specified in drinking water standards or regulations, the answer is yes. The gross organic load is high, but not much more so than the normally treated well water. Nevertheless, a certification of potability has been made by the legally authorized agency, the State of Maryland.

The second area of concern related to potability is the nature of the raw water source. A long-standing concept, as stated in the 1962 Public Health Service Drinking Water Standards (10), is the following:

> "The water supply should be obtained from the most desirable source which is feasible, and effort should be made to prevent or control pollution of the source. If the source is not adequately protected by natural means, the supply shall be adequately protected by treatment."

In terms of the intended goal of this water renovation system, namely the augmentation of the limited non-community well water source for the Sterling plant, other possible available sources should be considered, using the above concept. The local community, Oakland, will not and cannot provide additional water to the Sterling plant. The only other possible source is the Little Youghiogheny River, often not more than a small creek, polluted immediately upstream by raw, municipal sewage from Oakland. It is thus apparent that in terms of the concept of most desirable feasible source, the renovation system meets that criterion. It must also be emphasized that the renovated water, studied in Phase 2, will receive the additional full-scale, normal water treatment during the Phase 3 trial period of reuse. In this sense it may also be regarded as a raw water source, and certainly a most desirable one.

Nevertheless, one can and perhaps should put aside this legal question of potability and consider the following question. If this renovated water were to be recycled into the plant as described and used as intended, would there be any significant, discernible risk to the consumers of the chickens processed there? It is our considered judgment after weighing all the results of this study and that which preceded it, that the Phase 3 trial period of full recycle and reuse should proceed, and that the public health will not be jeopardized in so doing. In view of the urgent need to conserve our water resources, limit waste discharges, and improve water quality, the nation will have to proceed to selective reuse of wastewater. Such a project as this is a useful step in that direction.

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REFERENCES

1. Clise, J.D., Poultry Processing Wastewater Treatment and Reuse, Environmental Protection Technology Series, EPA-660/2-74-060, U.S. Environmental Protection Agency, Washington, D.C., March, 1974.

2. Huber, W.G., Carlson, M.B., and M.H. Lepper, "Penicillin and Antimicrobial Residues in Domestic Animals at Slaughter," J. Amer. Vet. Med. Assoc., 154, 1590-1595 (1969).

3. Read, R.B.,Bradshaw, J.G., Swartzentruber, A.A., and A.R. Brazis, "Detection of Sulfa Drugs and Antibiotics in Milk," Applied Micro., 21, 806-808 (1971).

4. Buelow, R.W., Carswell, J.K., and J.M. Symons, "An Improved Method for Determining Organics by Activated Carbon Absorption and Solvent Extraction - Part 1, " J. Amer. Water Works Assoc., 65, 57-72 (1973).

5. Bellar, T. and J.J. Lichtenberg, "Determining Volatile Organics at Microgram-per-litre Levels by Gas Chromatography," J. Amer. Water Works Assoc., 66, 739-744 (1974).

6. Symons, J.M., Bellar, T.A., Carswell, J.K., DeMarco, J., Kropp, K.L., Robeck, G.G., Seeger, D.R., Slocum, C.J., Smith, B.L., and A.A. Stevens, "National Organics Reconnaissance Survey for Halogenated Organics," J. Amer. Water Works Assoc., 67, 634-647 (1975).

7. Shackelford, W.M. and L.H. Keith, Frequency of Organic Compounds Identified in Water, Environmental Monitoring Series, EPA-600/4-76-062, U.S. Environmental Protection Agency, Washington, D.C., December 1976.

8. Hamza, A., Saad, S., and J. Witherow, "Water Reuse in Poultry Processing: Case Study in Egypt," THESE PROCEEDINGS.

9. Maier, W.J. and H.L. McConnell, "Carbon Measurements in Water Quality Monitoring," J. Water Pollution Control Feder., 46, 623-633 (1974).

10. U.S. Public Health Service, Drinking Water Standards, 1962, U.S. Department of Health, Education and Welfare, Washington, D.C.

WATER REUSE IN POULTRY PROCESSING:
CASE STUDY IN EGYPT

by

Ahmed Hamza*, Samia Saad*, and Jack Witherow**

The past decade has been marked by unprecedented global activity directed toward man's concern for environmental quality. In many nations, this concern has been translated into initiation of intensive research programs and adoption of strict measures to protect and enhance the quality of the environment.

In Egypt, population and industrial growth have made increasing demands on the scarce water resources, and at the same time people are demanding upgrading of water quality for public health, aesthetic and recreational purposes. The emergence of these paradoxical demands has presented a problem in providing water to meet the rising demands and obtaining the desired water quality. In addition to this problem, the poultry industry faces a unique situation, since new production farms and processing plants will be located in remote areas as a part of an integral plan to revive the Egyptian deserts. The stringency of water supply for the new plants coupled with the compelling need for prodigious quantities of water have led to the recognition of used water as a vital part of the water cycle in poultry processing.

Despite the considerable research efforts which have been devoted to the problem of water renovation and reuse in poultry processing (1,3), little has been done to implement the accumulated information in long term field studies. Water recycling in poultry processing is restricted as it confronts public health regulations and established traditions.

Recognizing that applied research is needed in this vital area, Alexandria University was awarded a U.S. Environmental Protection Agency grant to study application of water recycling in poultry processing. Field studies were initiated at Alexandria Poultry Processing Plant (APPP), during April 1976.

Research efforts in the first phase of the study were directed toward evaluation of water and poultry characteristics during processing, and documentation of necessary information for selection of potential sources of water for reuse. The second phase will focus on application of a multiple water reuse system, assessment of its technical and economic aspects and most important its impact on sanitation of the process and product.

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UNIT OPERATIONS AT APPP

A detailed discussion of the operations at APPP will not be attempted since it is almost identical to those in the U.S. and has been discussed in considerable detail by previous authors (1, 4). However, a brief description of several unit operations at APPP is necessary for understanding the available water sources for reuse.

A flow diagram of APPP and water usage by various operations is shown in Figure 1 and Table 1, respectively. Table 1 is based on 69 sets of observations from May to September 1976.

Killing and Bleeding

The live birds are stunned by low voltage current, and slaughtered by cutting the jugular vein and allowing the blood to drain in a restricted area. A sizable waste load is associated with this area due to the loss of blood to the sewer system.

Scalding and Defeathering

Birds are subscaled at 54-60°C, while adjusting the daily overflow to 5 liters per bird, (l/bird). The scalder effluent is highly contaminated with bacteria, blood and other residues. The scalded birds are defeathered in three consecutive picking machines, and the feathers are flumed to the rendering area using the effluents from the scalder and pickers in addition to fresh water. Water used in this area accounts for 28.3% of the total water usage.

Evisceration

The carcass cavity is opened for removal of entrails. Giblets are cleaned and wrapped for bulk selling. After opening and washing the gizzard, they are transferred manually to the wrapping area without fluming to save water and to eliminate the problem of treating the fluming effluent. The inedible viscera are dropped into a trough which is flushed by water from the hand washing faucets located along the evisceration line.

Washing and Chilling

The eviscerated carcasses are washed with fresh water in a horizontal immersion tank. The daily water usage averages 2 l/bird. Chilling is accomplished in two consecutive tanks at a combined daily overflow rate of 2 l/bird which is equal to USDA requirements. Effluents from both operations are discharged to the offal flume.

Other Water Uses

The screened feathers and offal are cooked at high pressure and temperature to produce poultry feed. The steam condenser has once-through water usage which averages 95 cu. meter of fresh water per day. In addition, about 50 cu. meter of fresh water are used daily to cool the ammonia compressors which operate continuously to refrigerate the storage coolers and produce ice used in the chilling operation.

ANALYTICAL PROCEDURES

Chemical analyses were performed in accordance with the "EPA Methods" (5). Samples for trace metal analyses were concentrated according to a method described by Price (6), and measurements by atomic absorption techniques were in accordance with "Standard Methods" (7).

Water samples for bacteriological analyses were collected in 100 ml sterile glass containers, while carcass samples were kept in specially prepared sterile polyethylene bags. To each bag 0.2 liter distilled water was poured followed by shaking for 5 minutes. The washing was poured on a sterile funnel and filtered through sterile No. 1 filter paper. Bacterial counts were made according to the procedures of "Standard Methods" (7).

CHARACTERISTICS OF POULTRY AND PROCESS EFFLUENTS

The waste loads of all operations presented in Table 2 and Figure 2 were calculated from average flow, concentration and production data. From each wastewater sample point (Figure 1), six sets of composite samples were collected during July and twelve sets of grab samples were collected between April and August. The average values for the twelve grab samples were generally higher than the average value for the six composite samples. A summary of the data from the grab samples is presented in Table 3 to characterize the wastewater effluents. The results indicate that the compressor cooling water is virtually clean, except for trace contamination by ammonia leaked from the compression cylinders. This water is suitable for reuse in the scalding or defeathering operations. The COD for most effluents was highly correlated to BOD_5, Total Residue (TR), and Total Volatile Residue (TVR), which implies the possible use of COD as an indicator of pollution in poultry processing.

Discharge of the washing and chilling effluents to the offal flume results in noticeable dilution of the concentrated effluent from the evisceration process. The mean concentrations of COD and Total Residue are less in chiller II than in chiller I or in the washer. This offers an opportunity for reuse of water from chiller II in chiller I and the washer.

Trace metal concentrations in various effluents are shown in Table 4. The relatively high iron concentration in the killing, scalding and eviscerating effluents is attributed to the blood contamination and the possible corrosion of fittings and pipelines at elevated scalding temperatures. Trace metal concentrations in the compressor cooling water are nearly identical to those in the fresh water. In general, concentrations of trace metals in various effluents are similar to those of fresh water, which indicates the near absence of pollution by trace metals during poultry processing. Magnesium and iron concentrations exceed the desired levels for drinking water in the U.S.

Antimicrobial residues in the effluents from the scalder, evisceration trough, washing and chilling tanks were tested according to the method suggested by Huber (8). The tested samples were either free or contained antimicrobial residues less than the sensitivity limit of 25 μg/l of chloramphenicol. In addition, four sets of wastewater samples were found free of parasites, except for the bleeding and killing effluent in which *Ascaridia* was detected twice.

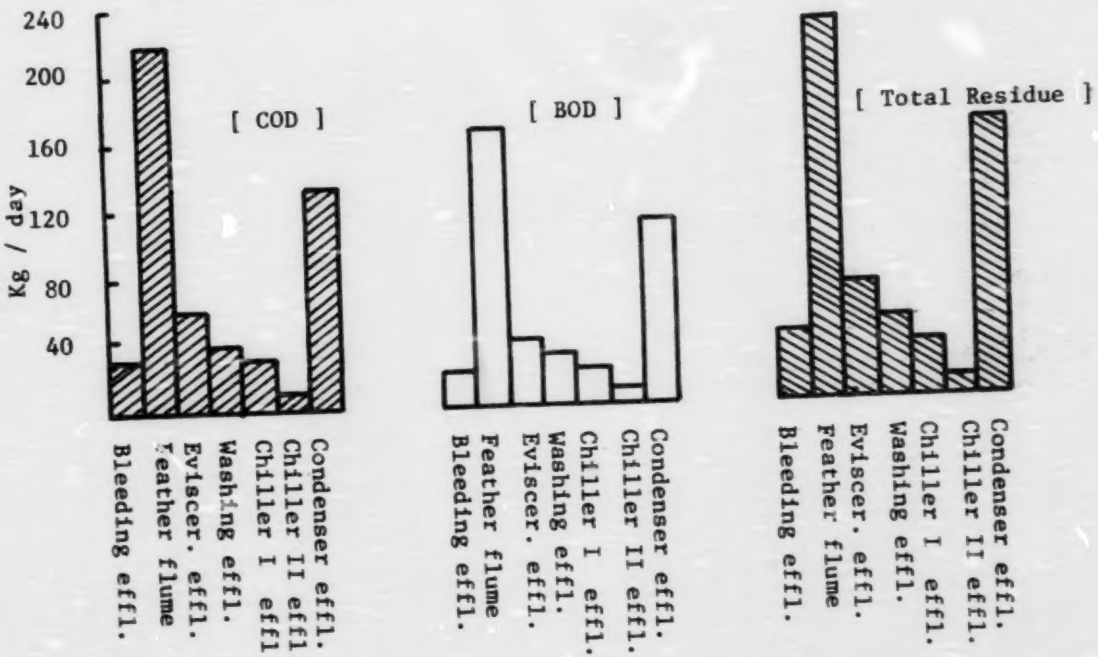

Figure 2. WASTE LOADS OF POULTRY PROCESSING OPERATIONS

TABLE 4. TRACE METALS IN GRAB SAMPLES OF WASTEWATER FROM APPP
(μg/1)

Sample		Co	Cr^{+6}	Zn	Ni	Pb	Mn	Cu	Fe	Cd
Final Effluent	R	2-16	2-17	34-117	1-6	1-12	19-180	23-60	130-800	2-3
	$\bar{X}$	5.8	5.6	61.8	3.0	3.6	72.3*	36.1	485 *	2.1
	S.D.	4.7	5.1	39.0	1.9	3.7	51.7	11.3	220	0.4
Bleeding Effluent	R	1-18	1-13	25-200	1-4	1-12	21-210	20-40	180-630	1-4
	$\bar{X}$	7.0	4.9	68.9	2.6	2.8	61.4*	27.1	470 *	3.0
	S.D.	5.7	4.0	60.5	1.1	4.1	66.2	7.2	165	1.1
Scalding Effluent	R	1-18	1-12	21-170	1-5	1-14	26-210	21-40	201-810	1-6
	$\bar{X}$	7.1	6.0	57.4	2.6	3.5	62.5	29.4	524	2.7
	S.D.	5.3	4.2	48.1	1.4	4.6	62.9	7.8	222	1.6
Feather Flume	R	2-15	0-12	22-190	2-5	1-12	13-180	15-40	215-640	1-4
	$\bar{X}$	7.4	5.4	64.3	3.4	3.0	53.3*	28.3	427 *	2.9
	S.D.	4.2	4.9	54.3	1.2	3.7	55.0	7.6	132	0.1
Evisceration Effluent	R	1-17	1-8	31-150	1-4	1-14	14-130	20-40	210-730	1-5
	$\bar{X}$	7.8	4.4	64.5	3.1	2.9	53.5*	30.6	466 *	2.7
	S.D.	5.9	3.1	37.9	1.3	4.5	36.1	6.8	165	1.4
Offal Flume	R	1-17	1-14	28-130	1-5	1-22	13-140	20-40	310-530	1-4
	$\bar{X}$	7.8	5.3	67.5	3.0	4.1	49.5	28.0	419	2.3
	S.D.	5.8	4.9	34.4	1.5	7.3	40.8	8.1	68	1.0
Washing Effluent	R	1-17	1-12	28-90	1-8	1-12	12-72	20-40	190-400	1-2
	$\bar{X}$	6.3	5.8	62.0	3.5	4.0	26.7	29.7	311 *	1.8
	S.D.	6.3	4.0	25.8	2.6	4.6	22.5	6.4	95	0.5
Chiller I Effluent	R	2-19	1-8	21-110	1-9	1-10	10-160	21-180	90-500	1-3
	$\bar{X}$	8.3	3.8	66.4	3.6	3.3	44.0	51.9	279	2.4
	S.D.	5.2	2.8	27.4	2.7	3.9	52.2	53.7	142	0.8
Chiller II Effluent	R	3-18	1-6	30-120	1-5	1-9	10-220	18-32	210-650	1-3
	$\bar{X}$	9.1	3.4	68.4	3.1	3.5	61.4*	27.1	374 *	2.0
	S.D.	4.7	1.9	34.1	1.6	3.3	86.3	6.0	147	0.8
Condenser Effluent	R	2-14	1-9	26-140	1-9	1-8	9-140	13-100	240-890	1-5
	$\bar{X}$	8.3	3.5	61.5	3.7	2.3	50.3	38.7	454 *	2.6
	S.D.	3.8	3.1	44.7	2.9	2.8	58.7	35.2	255	1.8
Compressor Cooling	R	2-18	1-15	32-190	1-12	1-14	10-190	9-40	120-600	1-3
	$\bar{X}$	7.9	4.9	70.1	3.1	2.8	63.5*	25.4	362 *	2.0
	S.D.	4.7	4.4	53.1	3.7	4.6	66.3	12.8	155	0.2
U.S. Drinking Water Standards		--	50	--	--	50	50	1000	300	10

*Values exceed drinking water standards
R = Range X = Mean S.D. = Standard Deviation n = 8

Bacterial identification and counts of the various effluents are shown in Table 5 and the counts are illustrated on Figure 3. The highest counts were found in the killing and eviscerating effluents. Less contamination was observed in the scalding and feather flume effluents. This may be due to a reduction of viable cells from scalding or by dilution with fresh water.

The decrease in bacterial counts in the offal flume in comparison with the eviscerating effluent is due to the dilution effect of the washing and chilling effluents. The most prevalent bacteria in the effluents were E. coli, Pseudomonas, and Proteus. Salmonella, Para colon, Shigella, and Staphlococci were identified in several samples. Cooling water from the compressors was generally free from bacterial contamination.

The results presented in Table 6 and Figure 4 show the identified bacteria and/or counts associated with the carcass samples. Heavy contamination was encountered after both scalding and evisceration. Washing decreased the bacterial counts on the carcasses by 3 to 4 orders of magnitude and chilling decreased the bacterial counts by 2 additional orders of magnitude. The bacterial counts increased again during the final weighing and packaging operations. This striking recontamination indicates the need to modify the process by eliminating or minimizing the human contact during the weighing and packaging operations.

The bacteria associated with the carcasses were similar in their order of prevalence to those found in the wastewater effluents.

ACCUMULATION OF CONTAMINANTS IN THE PROCESS WATER

A study of buildup of contaminants in the scalding, washing, and chilling tanks was undertaken to provide information concerning the quality of water which comes in direct contact with the carcasses during processing.

The usual operation involves initial fillings of the tanks every morning and discharging the used water and refilling with fresh water once or twice during the processing period. Refilling frequencies depend on the operator's judgement for the need to renew the process water.

During this study no refilling was done. However, overflow from the tanks was kept constant according to the rates previously mentioned. Water samples were taken from the tanks after one hour of operation, and every hour after that for a total period of six hours. Samples were not collected during the lunch hour. This sampling scheme was repeated four times in May.

Accumulation of total aerobic and coliform counts in the process water is illustrated in Figures 5 and 6, respectively. Bacteria contamination of the scalding water was greater than in the washing and chilling waters. During the first processing period (8-11 a.m.) bacterial counts in all tanks increased, and continued to increase during the second processing period (12-3 p.m.). The results of this study support the value of continual removal of water contaminants in these "immersion processes".

TABLE 5. BACTERIA IDENTIFICATION AND COUNTS OF WASTEWATER SAMPLES

(Percent of Positive Results)

Sampling Station	No. of Observations	Escherichia coli	Proteus	Pseudomonas	Salmonella typhi	Salmonella para typhi A	Salmonella para typhi B	Para colon	Shigella	Staphlococci	Streptococci	Micrococci	Monila	Total Aerobic (1)	Coliform(1)
Final Effluent	19	76	10	57	5	5	5	23	5	19	5	5	11	$9.9\text{x}10^8$	$4.3\text{x}10^6$
Scalding Effluent	18	66	16	11	5	32	22	32	66	77		11	5	$3.3\text{x}10^7$	$2.9\text{x}10^5$
Feather Flume	21	100	23	5	5	5	5	9.5	9.5	19			14	$3.5\text{x}10^7$	$4.0\text{x}10^5$
Eviscerating Trough	21	95	33	33				5	9.5				14	$6.4\text{x}10^{11}$	$7.4\text{x}10^{10}$
Offal Flume	21	95	39	19	9.5	5	9.5	19	5	14	5	19	5	$1.9\text{x}10^8$	$2.7\text{x}10^6$
Wash Tank	20	85	33	28	5	19		28	14	9.5	14	28	9.5	$1.0\text{x}10^5$	$2.0\text{x}10^3$
Chiller I	21	85	33	57	9.5	9.5	5	9.5	9.5	5	14	14	5	$4.9\text{x}10^4$	$2.1\text{x}10^3$
Chiller II	21	76	14	62	23	9.5		19	5	14	5	14	5	$6.9\text{x}10^4$	$1.3\text{x}10^3$
Condenser Water	14	64	28		14	14	7	7			7	7		$1.2\text{x}10^4$	$1.5\text{x}10^3$
Compressor Water	14	28		14	7									$1.1\text{x}10^2$	-------

(1) Average counts per ml

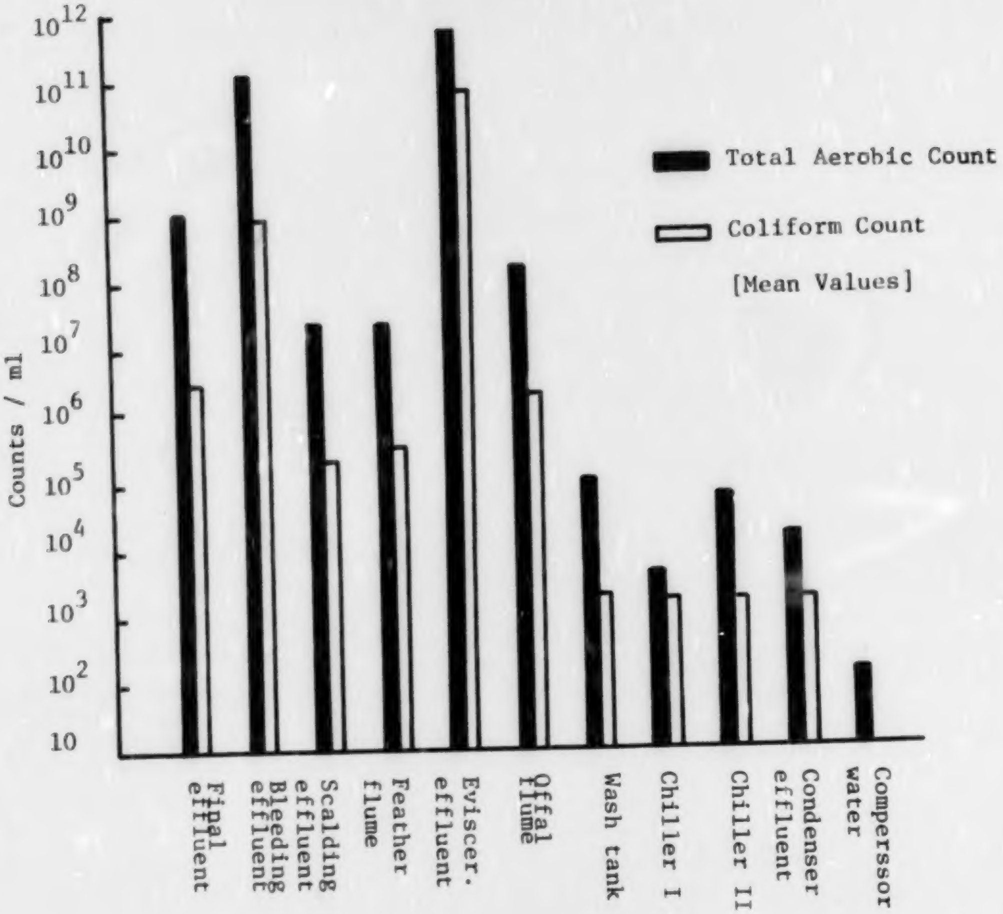

Figure 3. BACTERIOLOGICAL COUNTS OF WASTEWATER

TABLE 6. BACTERIA IDENTIFICATION AND COUNTS OF PROCESSED CARCASSES

(Percent of Positive Results)

Sampling Station	No. of Observations	Escherichia coli	Proteus	Pseudomonas	Salmonella typhi	Salmonella para typhi A	Salmonella para typhi B	Shigella	Streptococci	Micrococci	Monilia	Total Aerobic(1)	Coliform(1)
After Scalding	18	72	16.6	11.1						5.6	33.3	1.8×10^9	1.7×10^7
During Eviscer.	18	88.9	38.9	50.0	16.0	5.7	5.7	11.1		11.1	33	3.0×10^{12}	4.4×10^{10}
After Eviscer.	12	83.3	25	58.3	8.3						25	3.9×10^{12}	4.6×10^{10}
After Washing	12	100	8.3	16.7	16.7					16.7	25	2.2×10^8	9.6×10^6
After Chiller I	12	100	33.3	41.7	25.0	8.3	8.3	16.7	25.0		25	1.6×10^6	9.8×10^4
After Chiller II	18	88.9	44.4	38.9	27.8	11.1	33.3				33.3	1.9×10^6	5.6×10^4
During Weighing	12	100	33.3	75.0		8.3			25.0	8.3	25	1.6×10^7	4.2×10^5
After Packaging	18	77.8	27.8	66.7	22.2	11.1	27.8	16.6	55.6		17	4.6×10^7	3.7×10^6

(1) Average counts per carcass.

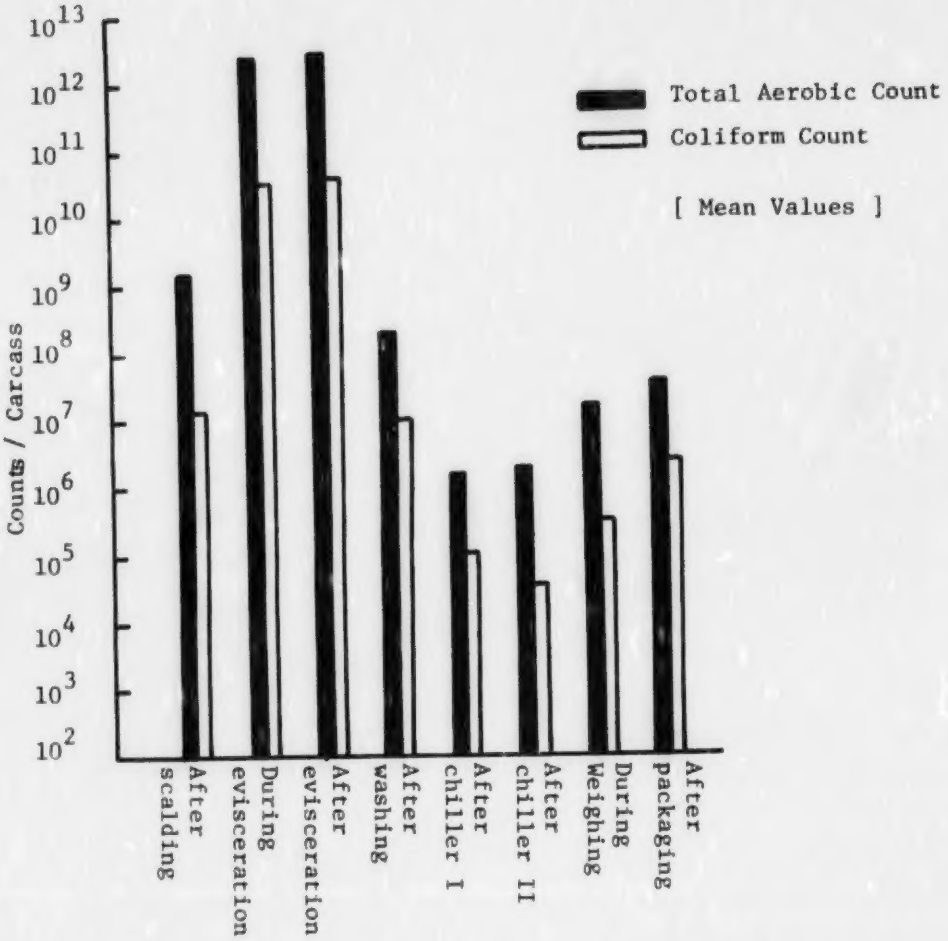

Figure 4. BACTERIOLOGICAL COUNTS OF CARCASSES

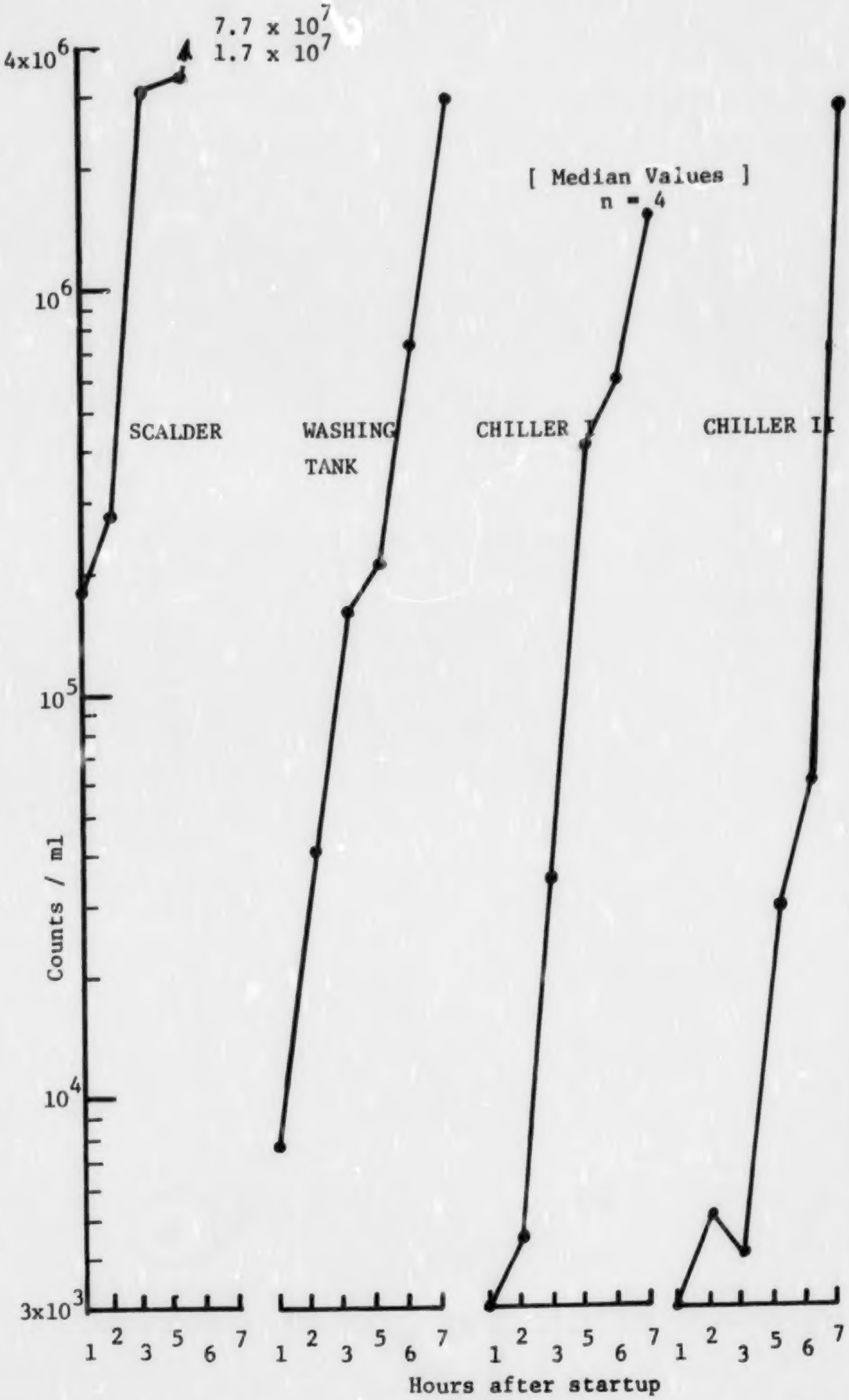

Figure 5. Accumulation of Total Aerobic Count in Process Water.

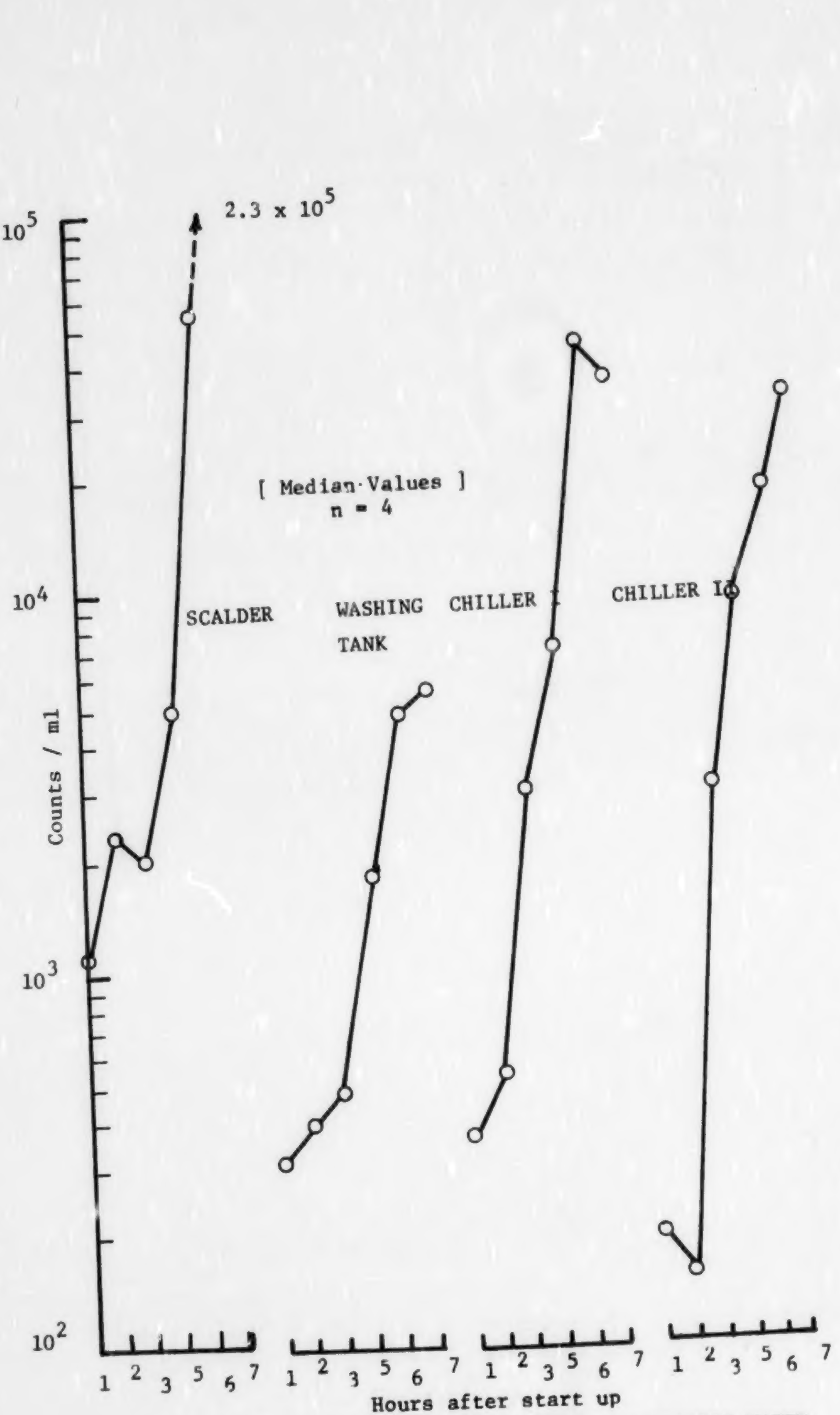

Figure 6. ACCUMULATION OF COLIFORM COUNT IN PROCESS WATER

To evaluate the effect of process water on the bacterial quality of the carcasses, the accumulation study was repeated 7 times during Nov./Dec. Figure 7 shows parallel deterioration of the bacterial quality of the carcasses as a direct result of the increased contamination of the process water.

DISCUSSION

Egyptian health regulations agree in principal with those of the USDA (9), which requires the use of potable water in all operations involving direct contact between water and the carcass or giblets. However, in the common water immersion and water transport operations used in poultry processing the potable quality is lost when the first carcass or giblet enters the tank or flume. The addition of fresh water does not regain potable quality but does cause considerable energy losses in maintaining water temperatures in the scalder and chillers.

The available option to save process water and conserve energy is water renovation and reuse. Although used water may not be potable, it can be treated to a better quality than the process water which is presently used in contact with the carcasses. Contrary to the popular belief, use of renovated water can result in improving the quality of the process water (10) and most likely the poultry products.

Present governmental regulations specify quality and quantities of freshwater in poultry processing to maintain processing methods which experience has shown satisfactory to obtain a product safe for consumption. The purpose of this research project is to demonstrate environmentally desirable modifications of water use in several unit operations which will maintain or improve the water quality in these operations and produce a product equally safe for consumption. Most of the data gathered in phase one has been to establish a baseline of water and product quality in each unit operation. This data is to be compared with similar data collected in phase two to document expected improvements in water and product quality.

MULTIPLE USE SYSTEM

The results of the first phase of the U.S. EPA demonstration project add support to the premise of water reuse in poultry processing. The multiple use system shown in Figure 1, has been initiated with the second phase of this project which began in March 1977.

The system involves use of fresh water in the final chiller and recycling its overflow after grease separation and bacterial reduction to the chiller I at a rate of 20-25 l/min. To supplement the need of the chiller I fresh water will be added at a rate of 12-15 l/min. Counter current flow of all the water from the final chiller to the chiller I cannot be applied because of insufficient chilling capacity at the plant. The overflow of chiller I will be reused with an equivalent flow of fresh water as a continuous feed to the washing tank. Effluent of the washing tank will be reused in the feather flume to replace the fresh water used in this operation. Water used for cooling the compressors will be reused as a continuous feed to the scalding tank, which will reduce both the fresh water and energy requirements

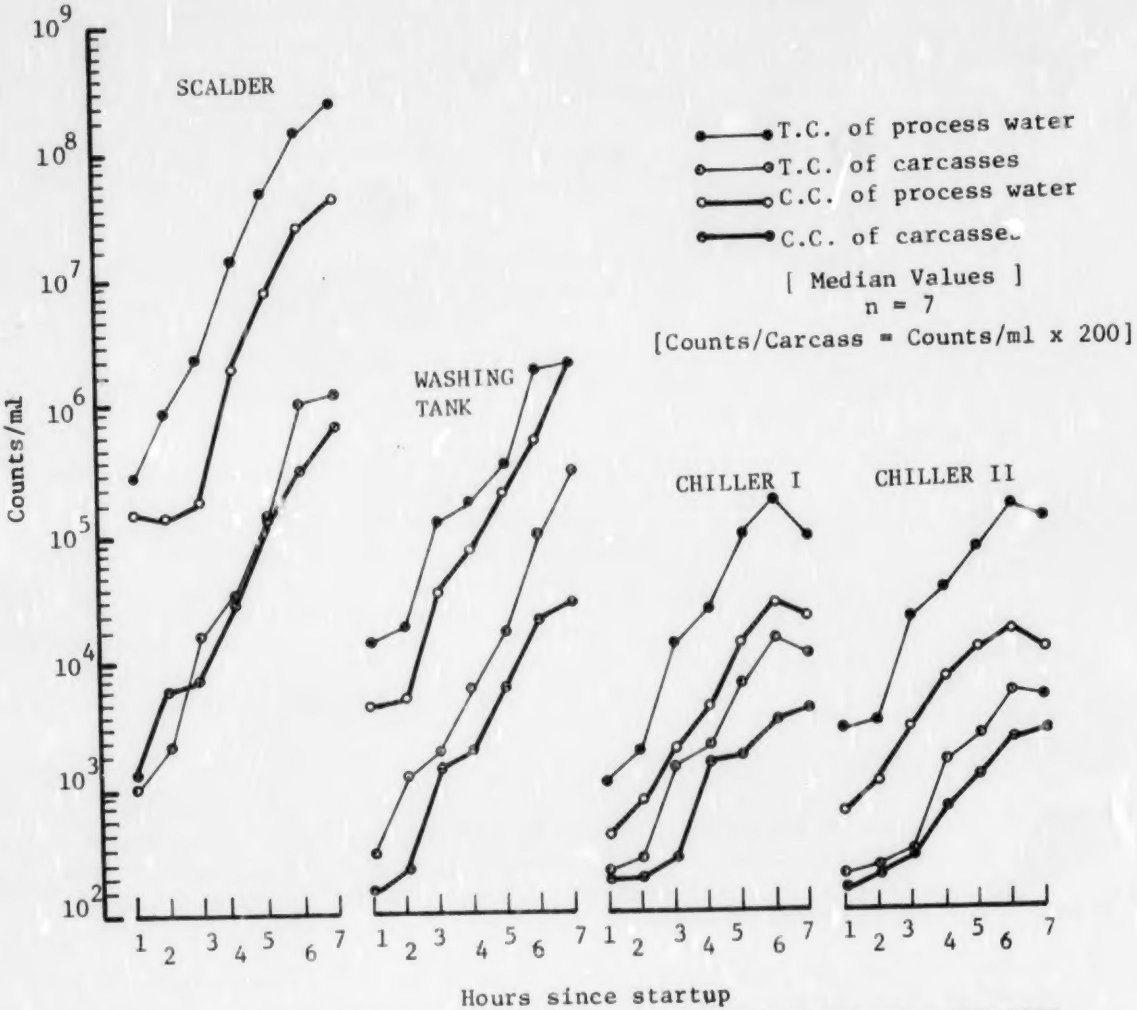

Figure 7. ACCUMULATION OF BACTERIA IN PROCESS WATER AND CARCASSES

of the scalding operation. This multiple system is flexible, since the ratio of fresh water/used water can be adjusted to insure the quality of the water used in each unit operation.

High pressure spray washers will replace the existing faucets of the evisceration trough to reduce water usage in this area. The trough will be modified to facilitate movement of the inedible viscera to the evisceration flume without flushing with water.

Multiple water use together with modifying the evisceration operation will save 40% of the current process water usage.

In the final phase of the study, the once through condensing water will be renovated and recycled continuously to the rendering cookers which will save an additional 25% of the water usage. Renovation is needed to remove grease, residues and volatile matter. Reduction of bacteria counts in the renovated water is not essential for this particular operation.

SUMMARY

The results obtained from this study have provided the following:

1. Manual handling during weighing and packaging results in noticeable recontamination of the processed carcasses. Elimination of human contact in this operation is required to upgrade the quality of the product.

2. Water used for cooling the compressors can be reused in the scalder without treatment as it is virtually free from contamination.

3. A study of accumulation of contaminants in the immersion processes (scalding, washing, and chilling) revealed a direct relationship between the bacterial counts in the water and on the carcasses. Continual renovation of water to retard the rate of buildup of contaminants is needed. Use of renovated water can enhance the quality of the process water in these operations, besides saving part of the energy required for cooling and heating processes.

4. Counter current water use through the chillers and washer is planned after applying renovation measures for grease and bacterial reduction.

5. A comprehensive evaluation of the water use system will be performed during the second phase of the study.

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REFERENCES

1. Berry L. S., et al. Sand Filtration and Activated Carbon Treatment of Poultry Process Water. Jour. Water Poll. Control Fed., 48:2394 (1976).

2. Hamza A., et al. Conservation of Water in Food Processing by Use of Low Volume High Pressure Sprays. The Third National Conference on Complete Water Reuse, AIChE and EPA, Cincinnati, OH. June 1976.

3. Clise, J. D. Poultry Processing Wastewater Treatment and Reuse. Envir. Prot. Tech. Series, EPA-660/2-74-060, Washington, DC. 1974.

4. Carawan, R. E., et al. Water and Waste Management in Poultry Processing. Env. Prot. Tech. Series, EPA-660/2-74-031, Washington, DC. 1974.

5. Manual of Methods for Chemical Analysis of Water and Wastewater. Tech. Transfer, EPA-625/6-74-003. 1974.

6. Price, W. J. Effluent and Water Treatment Jour., April 1967.

7. Standard Methods of Examination of Water and Wastewater. 13th Ed. Amer. Pub. Health Assn., New York, NY. 1971.

8. Huber, W. G., et al. Penicillin and Antimicrobial Residues in Domestic Animals. Jour. Amer. Vet. Med. Assoc., 154:1590. 1969.

9. Regulations Governing the Inspection of Poultry and Poultry Products. USDA, Consumer Marketing Service, Poultry Division. 1968.

10. Rogers, C. J. Recycling of Water in Poultry Processing Plants. Technical Report on Project S-800930, EPA, IERL, Cincinnati, OH. 1976.

THE TREATMENT AND DISPOSAL OF WASTEWATER FROM DAIRY PROCESSING PLANTS

by

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The concern over environmental quality has brought about the National Pollution Discharge Elimination System (NPDES), which has set limitations on the type and quantities of pollutants that may be discharged from the dairy processing and other industries. These increased standards have forced policy makers within the industry to review their present waste-handling systems and consider alternatives in order to comply with the above standards.

The three alternatives which are open to the processing plants are upgrade or install a private treatment-disposal system; connect to, or continue to discharge to, a municipal sewage treatment plant, most of which are reassessing the cost of treatment; or go out of business. Any of the above choices will result in an increase in the cost of the product to the ultimate consumer.

The objective of this project was to evaluate the cost of dairy products to the consumer as influenced by the new water pollution standards. To meet this objective and obtain this data, the effluent of some typical processing plants and several commonly-used treatment-disposal systems were monitored. This paper will report on the activities and results of this monitoring.

An inventory was conducted of the wastewater handling methods used by processing plants in Minnesota. It was found that only 271 dairy processing plants were in operation in November of 1975 compared with 563 in 1965. Most of the reduction had taken place with the smaller plants and milk-receiving stations. These transfer or receiving stations numbered 98 and their sole job was to collect and cool milk for shipment to the processing plant. Bottling plants number 39 and the remaining 134 plants represent some form of milk processing plant.

A break down of the type of waste-handling system was obtained from a mail survey in which 121 of the 271 plants responded. Over 68 percent of the plants discharge to a municipal sewage-treatment plant. Just over 16 percent of the plants utilize private waste-treatment systems, with septic tanks being the most common. Nearly 9 percent of the plants discharge to a water course directly without treatment and the remaining 6-plus percent remain unknown.

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Most of the 16 percent, or 44 plants, using private waste treatment systems were visited and evaluated as to their suitability for serving as typical of the industry. Six different types of plants were selected as typical plants with good treatment-disposal systems. These included ridge and furrow, single stabilization pond, two-cell stabilization pond, trickling filter, package aeration plant and two-stage aerated lagoon with chemical treatment. While on these field visits we also saw some of the plants that discharge without treatment. All of the operations discharging directly without treatment were small plants and transfer stations outletting into a natural swampy or low area. While not promoting this practice, it was noted that there appeared to be no negative effect of the surrounding natural environment.

Ridge and Furrow

The ridge and furrow system was not sampled as there is no system effluent. The several operations which were visited were functioning well and the management was well pleased in all cases. When properly designed, the management requirements are quite minimal. While the necessary size is a function of water use and soil type, a recommendation of 5,000 gallons of wastewater per acre-day (4.67 l/m^2-day) can be used to design a system (1). This is the winter rate (half the summer rate) which is recommended for areas which receive severe winter weather.

Single Stage Lagoon

Some sampling was done of the single-stage lagoon system. However, the discharge to surrounding pasture was never required, so no output data was available for this system.

Small Transfer Station With Package Aeration Plant

The data gathered in September from the small transfer station (or receiving station) with the package aeration plant are shown in Table 1. Sampling was also done in May and March but not included because of space limitations.* The total volatile solids (TVS) values in the influent (flow from the plant into the treatment system) are rather constant and reflect only the milk and wastewater from the can washer and the bulk tank. The values from the package plant (effluent) represent the discharge point and have been diluted by the addition (after the treatment plant) of the cooling water. This accounts for the low values shown for both TVS and chemical oxygen demand (COD).

The COD values are quite variable flowing from the plant and values jump by factors of 3 during the day. The data from Table 1 together with the flow data shown in Figure 1 are needed to get the complete picture of the mass load flowing into and out of the plant and treatment unit. The high COD values seen in the late evening represent a carry-over of the wash-down period because of the very low wastewater flow (almost zero) coming from other than the cooling water. The total system efficiency for TVS and COD were 27% and 67%, respectively.

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*All the data can be obtained upon request from the author.

TABLE 1. SMALL TRANSFER STATION WITH A PACKAGE AERATION PLANT - WASTEWATER ANALYSIS

INFLUENT 23-24 Sept. 75

Time	TS mg/l	TVS mg/l	COD mg/l	pH Units	Ortho Phos. mg/l	BOD mg/l
6:00 a.m.	2540	1240	1617	7	216	
7:00	2240	900	3823	7.5	270	
8:00	3460	1840	1260	7	225	
9:00	3600	2280	3206	7	258	2420
10:00	4060	2340	3289	7	348	
11:00	3400	1820	2704	8	258	
12:00	3940	2240	2633	7	371	
1:00 p.m.	3840	2180	2041	7	239	
2:00	5790	3720	5178	7	218	1183
3:00	4760	2900	3548	6	290	
4:00	4040	2680	5836	7	284	
5:00	6240	4060	7594	7	258	
6:00	6520	4300	7229	7	318	
7:00	4680	2920	7347	7	273	
8:00	4060	2440	8689	7	251	
9:00	6680	2900	6668	7	246	2121
10:00	4240	2620	7947	7	219	
11:00	3700	2140	7586	7	315	
12:00	2860	1500	3979	7	294	
1:00 a.m.	3820	2320	4286	7	229	
2:00	2960	1560	3438	7	194	
3:00	440	2640	3634	7	186	
4:00	4060	2340	1825	7	208	
5:00 a.m.	3200	1740	989	7	202	
AVE.	4130	2400	4431	7	257	

EFFLUENT 23 Sept. 75

Time	TS mg/l	TVS mg/l	COD mg/l	pH Units	Ortho Phos. mg/l	BOD mg/l
2:00 p.m.	1540	700	2080	7	70.5	792
3:00	1770	790	2590	7	94.0	891
4:00	1720	850	2881	7	125.5	1286
5:00			1610	7	83.1	898
6:00	1230	370	2100	7	83.6	891
7:00	1190	380	828	6.5	92.9	808
8:00	1150	450	848	6.5	125.0	919
9:00	820	80	322	7	128.9	352
10:00 p.m.	850	70	262	7	137.0	231
AVE.	1280	460	1502	6.9	104	785

This unit appeared to be underdesigned for the peak loads it was asked to handle during the working hours of the plant. The small aeration chamber and settling tank did not allow the system to benefit from the cyclic loading from the plant, and solids were carried through when the wash-down process would occur. This accounts for the low TVS treatment efficiency.

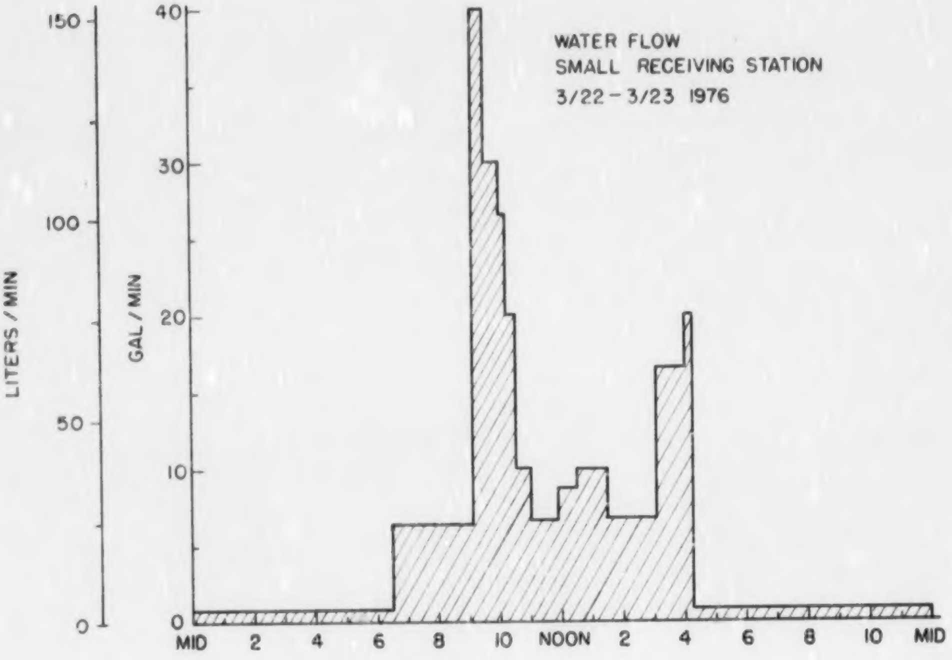

Figure 1. Water-flow rate to a small receiving station in March.

Transfer Station With Trickling Filter Treatment System

A larger transfer station was also sampled. This one was using a settling basin and trickling filter for treatment before discharging to a stream. The processing plant effluent and treatment system effluent was sampled in September, February and April. The February data are shown in Table 2.

The total solids (TS) data was less steady in this plant than the small transfer station with the TVS and COD values showing wide ranges of concentrations. The highest values were recorded when the first milk arrived in the morning and another peak occurred again around 4 p.m., which reflected the plant and equipment cleanup period. This is shown in Figure 2.

TABLE 2. RECEIVING STATION WITH TRICKLING FILTER TREATMENT SYSTEM - WASTEWATER ANALYSIS

INFLUENT 4-5 Feb. 76

Time	TS mg/1	TVS mg/1	COD mg/1	pH Units	Ortho Phos. mg/1	BOD mg/1
6:30 a.m.	1840	790	783	8.4	105	
7:30	2220	1370	1361	6.8	69	
8:30	3320	1120	1380	7.1	78	
9:30	2800	1540	3949	6.8	65	802
10:30	1800	840	1110	6.6	933	
11:30	1630	830	757	6.6	1064	
12:30 p.m.	2010	830	818	6.5	1026	
1:30	1860	560	463	6.4	546	
2:30	1600	850	988	6.5	277	927
3:30	2900	1650	2374	6.3	233	
4:30	2370	1120	1517	6.7	156	
5:30	3130	870	1002	10.4	59	
6:30	2860	900	1034	10.0	82	
7:30	2750	840	875	9.0	135	
8:30	2470	660	823	8.8	111	
9:30	2010	720	636	7.8	114	
10:30	2010	690	783	7.3	120	439
11:30	2130	660	784	7.8	119	
12:30 a.m.	2120	580	776	8.2	92	
1:30	2000	630	675	7.5	73	
2:30	1710	580	506	7.1	129	
3:30	2030	790	623	7.5	124	
4:30	2540	1330	1040	8.6	103	
5:30 a.m.	3260	1180	1280	8.3	137	
AVE.	2307	914	1097	7.6	248	

EFFLUENT 4 Feb. 76

Time	TS mg/1	TVS mg/1	COD mg/1	pH Units	Ortho Phos. mg/1	BOD mg/1
8:30 a.m.	880	260	89	6.8	66.3	
9:30	850	380	84	6.7	70.2	
10:30	950	330	121	6.7	193.4	101
11:30	960	430	146	6.7	170.3	
2:30 p.m.	800	370	78	6.7	104.5	
AVE.	888	354	104	6.7	121	

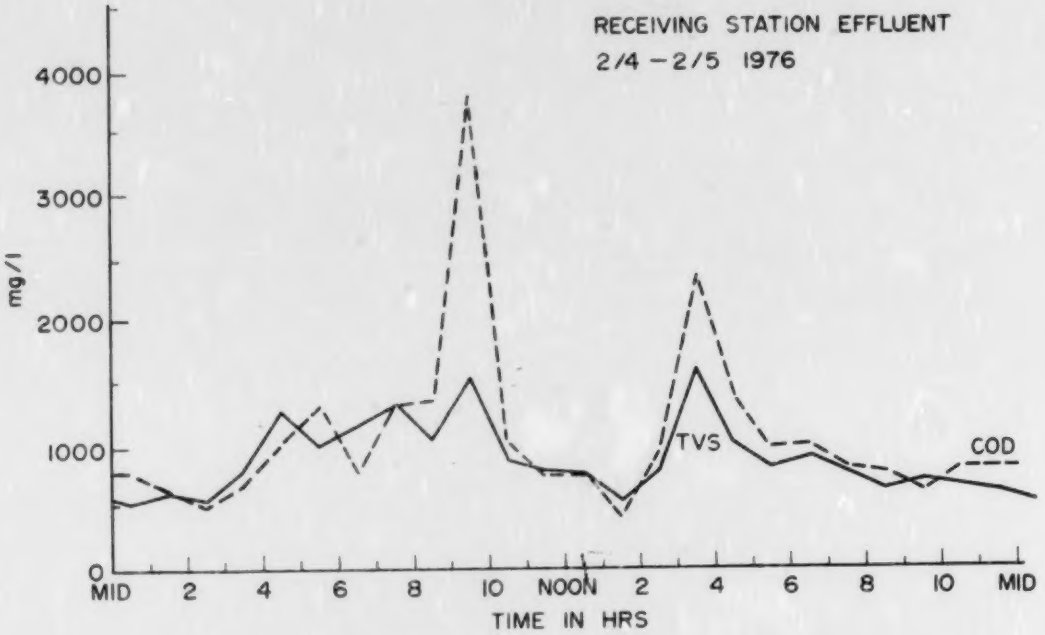

Figure 2. Twenty-four hourly values of TVS and COD for Receiving Station.

The high ortho-phospate values recorded about noon were not found on the other two sampling periods. The other data were much more consistant and lower, with the average values being 35 and 18 mg/l. It was suspected that the primary source of ortho phosphate resulted from hand washing the bulk tanks of the trucks used to bring the milk to the plant. This is one activity that can be managed to help reduce the loading to any treatment-disposal system.

Another parameter worthy of note on Table 2 are the pH values. High pH values were observed about the time of the late-afternoon washup. This load could be detrimental to a biological treatment system and may require dampening, diluting or changing the cleanup chemical.

Coupling this information with the data on water use shown in Figure 3 may give some clue as to the activities in the plant. This plant has a high percent of its flow going to cool the milk. The wash-down water, while quite variable, was dampened with a rather large base flow of cooling water. The spikes were due to tank truck and equipment wash down.

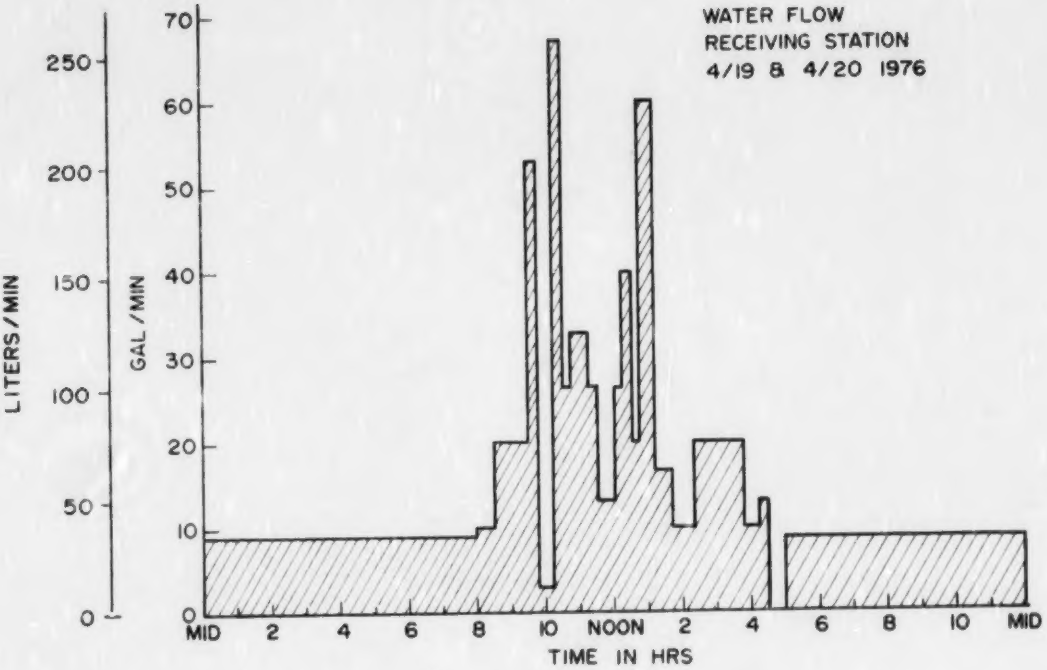

Figure 3. Water-flow rates to a receiving station in April.

Small Butter Plant With Two-Stage Lagoon Treatment System

A small, one-man butter processing plant utilizing a two-stage lagoon system proved to be the best waste-treatment system. Typical of processing plants, the water use was less variable than the preceding transfer stations due to the rather uniform water use of the various processing component. For a complete breakdown of the water use in the dairy industry, the reader is directed to Water and Wastewater Management in Dairy Processing, by Carawan, Jones and Hansen (2).

The flow for the small butter plant is shown in Figure 4 and shows a significant percentage of water used for cooling. The greatest water use was during the working day and was rather uneven. This uneven flow cycle could cause problems to some treatment systems. However, the lagoon system was quite capable of receiving these daily slug loadings.

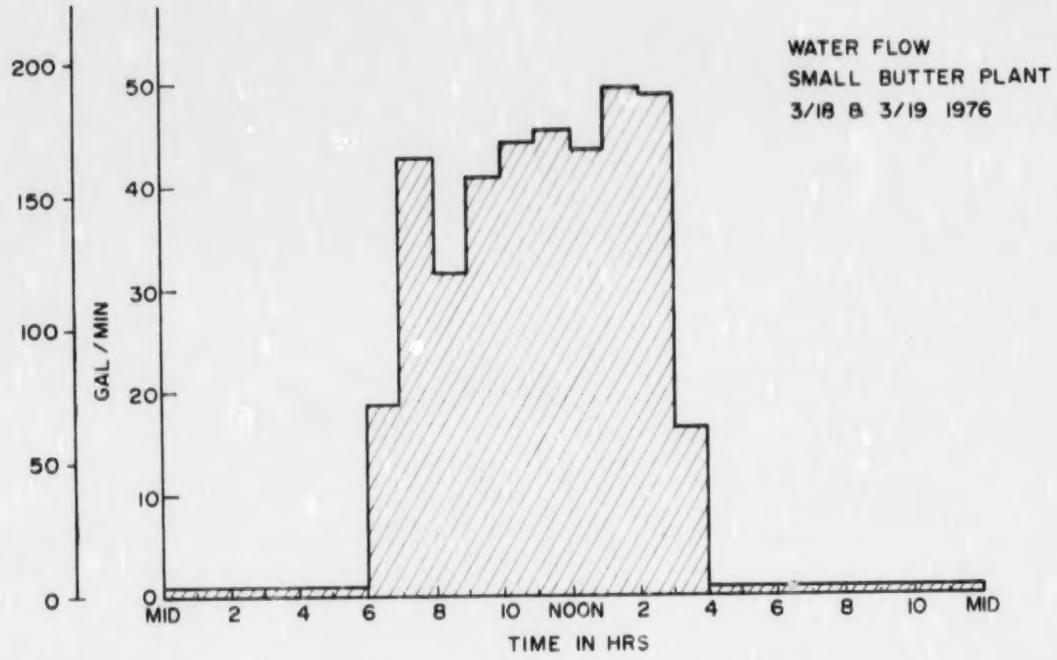

Figure 4. Water-use rate for a small butter plant.

The pumping station from the plant up to the first lagoon was sampled on a 24-hour basis, four times during the year and the September data are shown in Table 3. While the flow data was rather uniform during the day, the measured parameters, with the exception of pH, change quite drastically. The orthophosphate values are quite variable. There is some correlation between the high values recorded of ortho phosphate and the TS and COD values, but the pattern was not identical. These September ortho-phosphate values were higher, with an average of 15.3, and more varied than the other three samplings, which averaged 3.4, 11.1 and 5.5 mg/l for each of the other days.

Biochemical oxygen demand (BOD) drops about 98%, from 516 to less than 9 mg/l, after the plant stops operation. The TS and TVS dip to 25% of their peak values while COD values drop to almost 10% during the 8:30-to-9:30 a.m. sampling periods in the morning. These changes point out the hazards of grab-sampling wastewater stream flows. The peaks could be even higher as the hourly sampling represents only a partial picture of the real wastewater concentration versus time.

TABLE 3. SMALL BUTTER PLANT WITH TWO-CELL STABILIZATION POND TREATMENT SYSTEM - WASTEWATER ANALYSIS

INFLUENT
(SAMPLED AT PUMPING STATION) 16-17 Sept. 75

Time	TS mg/l	TVS mg/l	COD mg/l	pH Units	Ortho Phos. mg/l	BOD mg/l
6:30 a.m.	920	720	1243	7.5	.7	
7:30	7510	6900	932	7.5	127.2	
8:30	2180	1940	3236	7.5	37.1	
9:30	500	380	349	7.5	2.5	
10:30	920	200	340	7.5	103.0	
11:30	570	140	311	7.5	9.0	
12:30 p.m.	1260	480	89	7.5	41.5	
1:30	320	80	86	7.5	3.6	
2:30	1110	520	1280	7.5	10.4	
3:30	400	130	101	7.5	.8	516
4:30	500	60	133	7.5	2.4	
5:30	420	50	8	7.5	17.3	
6:30	410	140	8	7.5	1.4	
7:30	360	10	5	7.5	1.2	
8:30	340	120	10	7.5	1.3	
9:30	340	120	0	7.5	1.2	8.8
10:30	400	110	0	7.5	.9	
11:30	300	150	0	7.5	1.0	
12:30 a.m.	400	140	4	7.5	.8	
1:30	380	100	4	7.5	.7	
2:30	360	110	0	7.5	.7	
3:30	410	180	0	7.5	.7	
4:30	340	120	0	7.5	.7	
5:30 a.m.	340	170	0	7.5	.6	
AVE.	870	540	339	7.5	15.3	

EFFLUENT 16 Sept. 75

Inflow at First Lagoon	52	20	82	8.1	19	18
Flow Between Lagoons	45	5	100	7.9	18	64
Outflow	38	3	63	7.8	7	5

The COD values vary more in the September data than in the other three sampling dates. To indicate not only the variability of the sample strength but also the variability of operation within the day, Figures 5 and 6 are included. These show the low values recorded during the shut-down period and also some spikes of high concentrations occurring throughout the day. In comparing the two graphs, notice that the peak values came at quite different times of the day. A complete understanding of all the plant operations is necessary to identify the cause of the high-strength discharges.

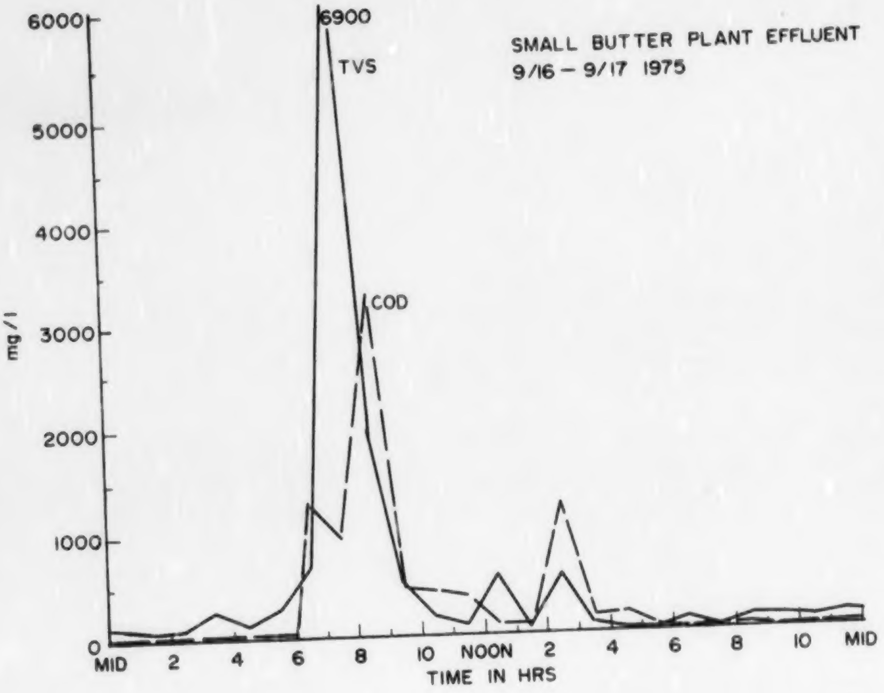

Figure 5. Concentrations of chemical oxygen demand and total volatile solids in the September effluent of a small butter plant.

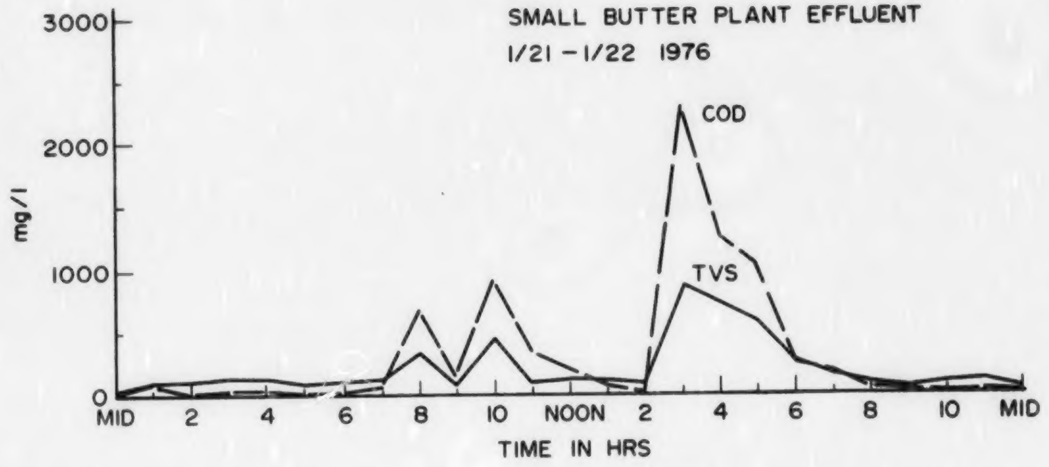

Figure 6. Concentration of chemical oxygen demand and total volatile solids in the January effluent of a small butter plant.

Large Cheese and Butter Plant With a Two-Stage Aerated Lagoon and Chemical Treatment

The selection of a typical large processing plant with a private treatment system was rather simple. As most large plants are in cities with central sewers and a treatment plant, very few have private treatment systems. This limitation made the selection of a typical plant easy but not necessarily representative. The large plant selected had just installed a new treatment system and can be used as a model to others.

The uniform water-use data, shown in Figure 7, is expected for a large, round-the-clock processing plant. The block steps are from the recordings and do not reflect sudden changes in the use rate. While a slight increase was seen through the middle of each day, the pattern was quite uniform.

One would suspect that a large, rather uniform flow would dampen or dilute high concentrations of various parameters in wastewater analysis. This trend was true for most of the day as seen from the data in Table 4. The striking exception is pH. The values range from 1 to above 10 with this full-scale change taking place between 5:30 and 6:30 in the morning. This would appear to be suspect data, however, the wide range and sudden change was also observed from the samples taken in February. This drastic range must result from a sudden dumping or washing of one section of the plant processing equipment. This range must be severely detrimental to any biological activity attempting to provide organic removal in the early stages of the system.

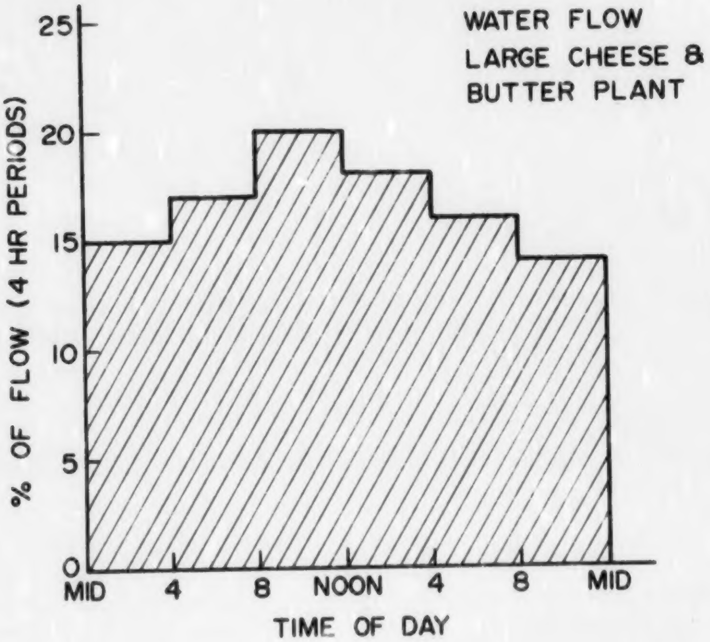

Figure 7. Twenty-four hour water-use data for a large cheese and butter plant.

A large batch of whey or solids was apparently dumped early on this morning as the TS and TVS are quite high in the 4:30 a.m. sample. The values are back to the average concentration in the next hour's sample. The ortho-phosphate values are quite uniform through the sampling period.

TABLE 4. WASTEWATER ANALYSIS FROM A LARGE CHEESE AND BUTTER PLANT DISCHARGING TO AN AERATED TWO-STAGE LAGOON WITH CHEMICAL TREATMENT

INFLUENT 3-4 May 76

Time	TS mg/1	TVS mg/1	COD mg/1	pH Units	Ortho Phos. mg/1	BOD mg/1
5:30 a.m.	4860	2460	10165	10.5	96	
6:30	3940	2320	2876	1.4	97	
7:30	5480	3520	6213	5.6	184	2205
8:30	3040	1640	3156	5.6	141	
9:30	2560	1520	2689	5.4	89	
10:30	3480	1280	2592	4.3	767	
11:30	3600	2200	4036	4.6	116	
12:30 p.m.	3560	1740	3831	6.2	124	
1:30	4040	1640	3060	9.0	149	
2:30	3680	1900	3377	5.4	153	
3:30	2940	1280	2163	9.0	148	3690
4:30			4348	5.3		
5:30	2540	1260	2870	5.4	117	
6:30	3080	1440	3105	5.4	92	
7:30	4420	2040	2926	5.1	95	
8:30	4400	2580	5178	5.1	130	
9:30	1900	880	2007	7.5	72	5640
10:30			3853	5.0		
11:30	2640	1440	2572	5.1	105	
12:30 a.m.	6620	5080	8893	4.2	177	
1:30	4240	2580	4992	5.3	374	
2:30	8320	3560	6913	12.0	66	
3:30	10180	6860	7773	2.0	255	
4:30 a.m.	22040	18360	7026	4.2	378	
AVE.	5071	3072	4442	5.8	179	

EFFLUENT 3-4 May 76

	TS mg/1	TVS mg/1	COD mg/1	pH Units	Ortho Phos. mg/1	BOD mg/1
3 May	3000	740	1035	9.0	1.5	1752
4 May	3130	780	954	7.0	1.4	1275

The effluent samples shown in Table 4 may indicate the need for additional settling. The TS values are high while the TVS and COD values reflect some treatment. The BOD values are quite high for effluent and certainly must be improved to meet current state standards. As this was the first year of operation, the management of treatment systems will likely improve the quality of the effluent with time and experience.

SUMMARY

The processing plants' effluent show a wide variation of both water use and concentration of those parameters measured. A summary of the average data is shown in Table 5. Reviewing this table for treatment efficiencies, the butter plant using a two-cell stabilization pond exhibited the highest treatment of both COD and TS. The package aeration plant treating the wastewater from the small receiving station had the poorest treatment efficiencies.

This may also support the value of a treatment system which can be operated effectively with little or no management requirements.

As expected, the summer and fall months do a better job of treatment while the winter and spring periods reflect the effect of the cold temperatures.

CONCLUSIONS

1. Transfer stations and small package plants have two distinct water uses, cooling and wash water.
2. Values of most parameters change sharply, reflecting special activities within the plant. This points out the danger of grab-sampling dairy processing plants.
3. Sudden changes in the concentration of some parameters, such as pH, may be detrimental to biological treatment components.
4. Water-use rates vary widely and nonuniform flow within some operations are undesirable for package treatment plants, but have little effect on the efficiency of lagoon systems.
5. The two-cell stabilization pond was the most efficient treatment of TS and COD.
6. The dairy processing industry can make very good use of treatment systems which require low management skills. The stabilization pond and ridge and furrow systems meet this requirement and perform very well in Minnesota.

TABLE 5. SUMMARY OF LABORATORY ANALYSIS OF INFLUENT AND EFFLUENT SAMPLES FROM FOUR MINNESOTA DAIRY PLANTS

Type of Plant	Approx. annual milk received x10^6 lbs.	Date of sample	Flow/ day, 1,000 gal.	Chemical Oxygen demand				Total solids			
				Influent	Effluent		Eff.	Influent	Effluent		Eff.
				kg/day	kg/day	mg/l	%	kg/day	kg/day	mg/l	%
Large cheese and butter plant using a two-cell aerated lagoon	499.	Feb 75	190.2	3,228	164.1	228	95	4,354	1,730	2,403	60
		May 76	187.0	3,131	668.7	945	79	3,444	2,061	2,912	40
Small butter plant using a two-cell stabilization pond	50.	Sep 75	22.0	61.1	0.3	4	99	137.3	2.1	25	98
		Jan 76	37.1	37.3	2.6	25	93	49.7	8.9	86	82
		Feb 76	22.9	32.9	1.9	22	94	55.9	6.5	75	97
		May 76	25.8	45.9	0.5	5	99	57.2	1.6	16	97
Small receiving station using a package aeration system	16.	Sep 75	7.0	25.0	0.9	30	97	23.8	6.9	260	71
		Mar 76	7.4	16.3	9.1	326	44	15.6	24.9	890	0[a]
		May 76	8.4	17.1	6.4	202	62	16.4	29.0	935	0[a]
Receiving station trickling filter	91.	Sep 75	18.2	35.7	14.9	217	58	92.7	53.0	770	43
		Feb 76	16.6	69.8	65.3	1,040	65	136.5	55.8	888	59
		May 76	19.8	68.5	8.9	119	87	92.6	52.5	700	43

[a] At the time samples were taken the concentration of total solids in the effluent exceeded the concentration in the influent. This emphasizes the variability that can occur in measures of waste concentration.

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REFERENCES

1. Schraufnagel, F. H. Dairy Waste Disposal by Ridge and Furrow Irrigation. Proceedings of the 12th Indiana Waste Conference, Purdue University, Indiana Agricultural Extension Series. May, 1957.

2. Carawan, R. E., V. A. Jones and A. P. Hansen. Water and Wastewater Management in Dairy Processing. December, 1972. Department of Food Science, North Carolina State University, Raleigh, North Carolina 27607.

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